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Reuse of Municipal Wastewater for Groundwater Recharge

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A survey of groundwater recharge operations with municipal wastewater effluent was conducted. It was found that this activity is being practiced at 10 sites in the U.S. with a total capacity of 77 MGD. The most successful employ percolation with alternate flooding and drying cycles. Well injection can be successful but only if rigorous control of injected water quality is maintained. Clogging of recharge wells is the major problem. Sufficient data have not been developed to define the movement of pollutants such as salts, trace organics or pathogens through groundwater as a function of soil characteristics, groundwater hydraulics, and groundwater characteristics. Thus, water quality requirements to insure successful recharge over a long period can not be defined quantitatively.

At the sites surveyed reasonable success has been achieved over periods ranging from 1 to 20 years. It is recommended that intensive monitoring of these and a few other new sites be continued and instituted to gather data on which rational design criteria can be based.

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REUSE OF MUNICIPAL
WASTEWATER FOR
GROUNDWATER RECHARGE

by

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Contract No. 68-03-2140

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report provides a comprehensive summary and evaluation of current efforts throughout the U.S. to recharge groundwater systems with treated municipal wastewater. Through these recharge programs, groundwater supplies are being replenished, saltwater endangered-aquifers are being protected, and water is being reclaimed for future reuse.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

ABSTRACT

A survey of groundwater recharge operations with municipal wastewater effluent was conducted. It was found that this activity is being practiced at 10 sites in the U.S. with a total capacity of 77 MGD. The most successful employ percolation with alternate flooding and drying cycles. Well injection can be successful but only if rigorous control of injected water quality is maintained. Clogging of recharge wells is the major problem. Sufficient data have not been developed to define the movement of pollutants such as salts, trace organics or pathogens through groundwater as a function of soil characteristics, groundwater hydraulics, and groundwater characteristics. Thus, water quality requirements to insure successful recharge over a long period can not be defined quantitatively.

At the sites surveyed reasonable success has been achieved over periods ranging from 1 to 20 years. It is recommended that intensive monitoring of these and a few other new sites be continued and instituted to gather data on which rational design criteria can be based.

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SECTION 1

INTRODUCTION

Groundwater in the United States has historically been a quantitatively minor water source whose chief use was in individual homes or small communities. Today, however, groundwater supplies a substantial percentage of the nation's water requirements. The conservation, protection, and replenishment of our groundwater resources has become increasingly important as our reliance on this water grows.

As populations increase, demands for groundwater supplies in many areas of the country have started to exceed the safe perennial yield limits of the basins, causing significant drops in water tables. This has forced authorities to seek alternate supplies.

One such alternate supply is treated municipal wastewater which can be recharged to replenish groundwater basins, to establish saltwater intrusion barriers in threatened coastal aquifers, or to provide further treatment for ultimate extraction and reuse. Currently, an average of 45 mgd is used in the United States specifically for these groundwater recharge purposes. This figure will have increased to nearly 60 mgd by late 1976, and to 77 mgd by 1977, when sites presently under design and construction are operational.

It should be emphasized that the inadvertent, uncontrolled recharge of treated effluent discharged to land, and the continuous release of septic tank wastes is vastly greater in magnitude than the volumes shown here from formal recharge programs.

Figure 1 depicts the rate of growth of recharge practices from 1963 to 1976. While ten operations certainly cannot be projected as indicative of a trend, the current studies underway definitely show support of a continued increase in effluent recharge practices.

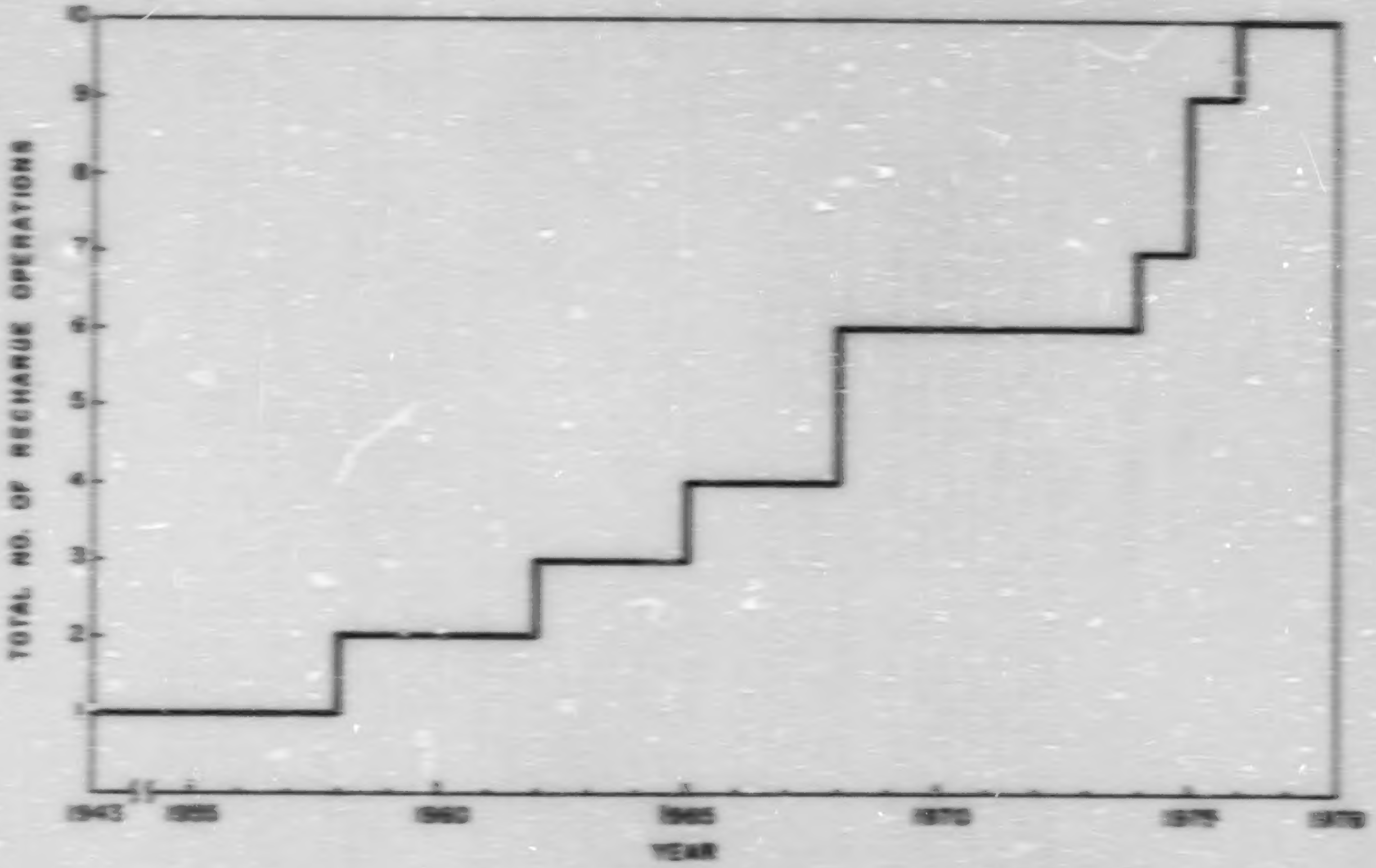

FIGURE 1.
GROWTH OF RECHARGE PRACTICES

SECTION II

SCOPE, OBJECTIVES, AND APPROACH

SCOPE

This study was limited to groundwater recharge of wastewater from municipal sewage treatment plants. Programs covered were those recharging for groundwater basin replenishment and/or to control salt water intrusion, and included those operations that extracted the treated effluent after recharge for irrigation and other uses. Sites practicing land application and percolation of effluent for irrigation or disposal purposes only were not included in this study.

A total of 10 sites in the U.S. were found to be currently operating effluent recharge systems, conducting pilot studies prior to designing full scale operations, or constructing facilities specifically for recharge. Each of these was investigated in a case study report. (See Appendix A)

It should be noted, however, that there are many locations practicing recharge with fresh water supplies (imported water, storm water, and natural runoff) that are not included here. Also, there exist many treatment plants across the nation (usually small, rural facilities) that are disposing of effluent on land or dry riverbeds, thereby ultimately recharging aquifers. These operations, along with thousands of individual septic tank facilities, are uncontrolled, unmonitored, non-deliberate recharge operations and are not included in this study.

OBJECTIVES

The primary purpose of this study was to make a state-of-the-art survey to bring together information about existing groundwater recharge operations in a concise form. This information can be used by planners and engineers in the design of new recharge systems and by governmental decision makers in determining whether such systems are appropriate to their situations. The report is also a useful tool for responsible management and technical personnel in locating existing recharge operations which can provide valuable background experience. Another purpose of the project is to spotlight deficiencies that exist in the available information concerning recharge with treated wastewater and to suggest further research to overcome these deficiencies.

Specific project objectives were as follows:

- Conduct a literature search to collect data on those projects for which publications exist, and also to obtain water quality criteria for recharge applications.
- Supplement the literature search by various means to locate and obtain descriptive information on unpublicized recharge projects and update existing information on publicized projects.
- Conduct field investigations of important recharge operations which are relatively little known.
- For each recharge situation, obtain technical and economic information pertinent to purpose, size, design, performance, costs, and problems.

APPROACH

The following tasks were performed by the SCS project team during the completion of this study:

- A comprehensive literature search was conducted at several large university libraries and in-house for any information pertinent to municipal wastewater recharge operations.
- Field investigations of ten recharge sites were made and case studies prepared (see Section VII, A).
- Separate sections were prepared using information from the case studies and other sources regarding required quality criteria, types of treatment, methods of recharge, monitoring and safeguards, significant operational problems, and economic factors.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- As the demand for fresh water continues to grow, and groundwater supplies become increasingly overextended, the problems of salt water intrusion along coastal areas and diminishing groundwater reserves are forcing authorities to look toward domestic wastewater reuse, including groundwater recharge, as a feasible conservation measure.

- Ten locations in the U.S. are currently operating or designing and constructing formal groundwater recharge facilities for treated municipal wastewater. Seven of these are percolation type programs, and three are well injection systems.

- Percolation recharge operations have been shown to be effective in forming subsurface barriers against salt water intrusion. The use of effluent for this purpose is likely to increase in coastal aquifers threatened by seawater.

- Preliminary studies(1) have shown that percolation of wastewater through soil provides significant treatment. Three of the recharge programs plan to take advantage of this phenomenon by extracting all recharged water for irrigation and recreational reuse.

---

(1) U.S. Water Conservation Lab, Phoenix, AR.
L.A. County Sanitation Districts, Whittier Narrows, CA.
Santee Co. Water District, Santee, CA.
City of Lake George, N.Y.

- Five of the locations studied (Whittier Narrows, CA; Camp Pendleton, CA; Hemet, CA; Oceanside, CA; and St. Croix, V.I.) replenish potable groundwater basins with treated wastewater, or a mixture of effluent and fresh water sources. None of these programs has ever recorded any deleterious effects due to effluent recharge activities. However, the difficulties of tracing the subsurface flow of recharged water, its mixing with existing groundwater, and the lack of testing for potentially hazardous trace constituents (residual organics, heavy metals, pesticides, etc.), leaves the matter still open to question.

- Recharge by percolation has several advantages over recharge by well injection: standard quality secondary effluent can be used successfully, capital costs and operation and maintenance requirements are minimal, and the soil provides exceptional tertiary treatment under proper operating conditions.

- Recharge by percolation is most successful when: the SS concentration in effluent is low (< 20 mg/l); infiltration rates are high (> 2 ft/day); and operation follows a cyclic flooding-draining-drying schedule to reduce surface clogging.

- No well injection recharge operations using treated effluent are currently operating in the United States. Preliminary tests at Palo Alto, CA, Orange County, CA, Los Angeles, CA, and Long Island, NY, have shown that injection recharge is feasible when high water quality is rigorously maintained and when the hydraulic and chemical characteristics of the receiving aquifer are compatible for recharge. The Palo Alto, Orange County, and Long Island programs are all in various stages of design and construction. The Los Angeles pilot study showed that the use of tertiary effluent in a well injection system was technically feasible but not economically competitive with the recharge of alternate fresh water supplies.

- Test injection studies have shown that successful well injection recharge requires high quality tertiary effluent (e.g., COD < 10 mg/l, SS < 1 mg/l, PO_4 < 1 mg/l, Fe < 0.5 mg/l, JTU < 0.5 units) with maximum allowable concentrations depending on the aquifer characteristics. Treatment prior to injection recharge usually requires chemical coagulation/settling, ammonia stripping or nitrification-denitrification, filtration, and carbon adsorption.

- Initial performance of pilot well recharge facilities has shown that full scale well injection programs should be preceded by extensive pilot studies to determine the hydraulic characteristics of the receiving aquifer and the necessary effluent quality for successful operation.

- To avoid buildup of TDS in groundwater basins, recharge programs replenishing aquifers with wastewater will ultimately have to provide some degree of demineralization to maintain proper salt levels. The need for demineralization depends on several factors: TDS of groundwater, TDS of effluent, volume of recharge water, volume and assimilative capacity of the groundwater basin, and extent of mixing with fresh sources before recharge.

- The future for groundwater recharge with treated municipal wastewater is uncertain at the present time. There exists a recognized lack of knowledge concerning residual organic materials: their composition, the types of long term affects, synergistic affects, methods of detection and identification, and the levels at which long term health affects are exerted. Until these questions are answered, most public health agencies are likely to follow the California Health Department's conservative stance in opposing new recharge programs to replenish potable aquifers.

RECOMMENDATIONS

- Before recharge for basin replenishment can be enthusiastically supported, further study into the fate of virus, trace organics, and toxic elements within the soil-aquifer environment is necessary. This includes the development of improved methods of tracing the movement of recharged waters, detecting and identifying potentially hazardous trace constituents, and collecting representative samples for analysis.

- One important area needing further examination is in the effect of operation techniques on pollutant removal efficiencies for percolation systems. For example, the U.S. Water Conservation Lab at Phoenix, Arizona, has shown that carefully controlled flooding-drying schedules can increase nitrogen removal from a normal 30 percent to over 80 percent. Perhaps the removals of virus, nutrients, trace organics, etc., can also be optimized by control of the upper soil environment by selective flooding-drying techniques.

- The ultimate need for demineralization to maintain salt levels in aquifers being recharged with higher TDS waters, as is usually the case with wastewater as the recharge source, has already been mentioned. Further study of the cost-effectiveness of various established and experimental demineralization systems is needed.

- The EPA and other concerned agencies should continue to support research and fund pilot projects such as those already receiving such aid at Phoenix, Arizona, Long Island, New York, Orange County, California, and Palo Alto, California. Groundwater recharge with treated wastewater for salt water intrusion barriers, for extraction and reuse, and for basin replenishment, is a potential water conservation and reuse practice that could be used to advantage by many communities.

SECTION IV

REQUIRED QUALITY CRITERIA

Augmenting the underground storage of water by artificial recharge provides a supplemental source of water for irrigation, for industrial and domestic uses, and/or a barrier to prevent salt water intrusion in coastal areas. A major prerequisite to recharge, however, is the perpetuation of an acceptable level of groundwater quality.

A groundwater basin system poses unique problems in (1) its tendency to concentrate pollutants within the soil solution and (2) its uncertain and slow purification once contaminated. However, the soil environment also acts to purify wastewater passing through it by the processes of mechanical filtration, adsorption, and ion exchange. Each groundwater system poses unique interactions between these phenomena.

REGULATIONS

There are currently no federal standards controlling the quality of water for recharge. However, as a result of the Safe Drinking Water Act, PL 93-523, passed by Congress in late 1974, it is anticipated that federal standards will be established in the near future.

Presently, regulations usually come from local or state Water Quality Control Boards and State Health Departments. For example, in California, the leading state in recharge programs, Regional Water Quality Control Boards are enacting basin plans that limit concentrations of contaminants in water to be recharged to basins within their jurisdictional area. Each basin carries its own requirements depending upon its quality, assimilative capacity, etc. Table 1 summarizes Water Quality Control Board regulations for recharge operations in the basin to be recharged by the Orange County Water District program (see case study report in Appendix A).

State Health Departments are beginning to play a larger role in regulating potable aquifer recharge operations. In California, the State Health Department is discouraging

Table 1. SANTA ANA REGIONAL WATER QUALITY CONTROL BOARD QUALITY REQUIREMENTS FOR WATER RECHARGED TO THE SANTA ANA GROUNDWATER BASIN

Constituent	Max. Concentration (mg/l)
Ammonium	1.0
Na	110
Total Hardness as Ca CO_3	220
SO4	125
Cl	120
Total N	10
Electrical Conductivity	900 (1)
Hexavalent Cr	0.05
Cd	0.01
Se	0.01
Mn	0.05
Barium	1.0
Ag	0.05
Cu	1.0
Pb	0.05
Hg	0.005
As	0.[illegible]
Fe	0.3
Fl	0.8
B	0.5
MBAS	0.5

(1) μ mho/cm

construction of new potable aquifer recharge systems and expansion of existing facilities until the potential health hazards of residual organics in treated wastewater can be proved insignificant (see Appendix C for complete Health Department statement).

PURIFICATION BY SOIL

Where groundwater systems are adaptable to recharge, wastewater purification by vertical and horizontal filtration through soil is highly effective. Results from testing at the case study locations of Whittier Narrows, California, and Phoenix, Arizona, show the following pollutant removals by percolation of secondary effluent through soil:

- Suspended solids are totally removed in the first few feet of percolation.
- Approximately 75 percent of the COD is removed in the first four feet, but below four feet the COD increases to 40 percent of the surface concentration.
- Total nitrogen removals can reach 80 percent in the first few feet of soil under proper system operation (see Phoenix case study, Appendix A).
- Phosphorus removal is dependent on travel distance through the soil with 50 percent removal after 30 feet, and 90 percent removal after several hundred feet.
- At Phoenix, fecal coliforms were reduced from 10^6 to generally less than 200 per 100 ml after 30 feet of vertical percolation, and additional lateral movement of 100 and 300 feet produced reductions to 10 and 0 per 100 ml, respectively.
- Virus studies at Phoenix (and previous well-documented studies at Santee, California) indicate that viruses are effectively removed by soil filtration.

FACTORS AFFECTING RECHARGE WATER QUALITY AND REQUIREMENTS

Requirements for recharge water quality may vary from location to location depending on several factors that affect soil purification capability and/or the recharged water's impact on the natural groundwater. Some of these factors are: soil characteristics, depth to groundwater table, native groundwater quality, assimilative capacity of the aquifer, distance and travel time to extraction point, and method of recharge.

Soil composition, such as the relative amount of clay vs. sand, determines such factors as cation exchange capacity, affecting the removal of metal ions and viruses and adsorptive capacity affecting the removal of trace organisms and solids. Porosity determines infiltration rates that affect residence time in surface layers which may in turn determine aerobic or anaerobic conditions. Impermeable clay layers may form localized barriers preventing uniform diffusion of recharged water. Thus, the total groundwater volume cannot be considered an effective diluting agent, and there may exist considerable variation in water quality both areally and in depth. (12, 16)

The depth to the groundwater table and distance to extraction point are important considerations in the removal of phosphorus and bacteria and perhaps several other constituents for which removals appear to be a function of travel distance.

Naturally, the quality of the groundwater should have a bearing on the recharge quality requirements. For example, a native groundwater of low TDS is more vulnerable to contamination by high TDS recharge water than an aquifer already high in salts. In some instances, however, quality requirements for successful hydraulic operation of injection facilities may be more stringent and will thus take precedence over requirements for protection of the native groundwater.

Quality requirements for recharge water should take into account the assimilative capacity of the receiving aquifer. If the recharged effluent volume is insignificant compared to the natural volume of the groundwater basin then quality regulations may not have to be as stringent as in the case where recharge represents a major portion of the aquifer volume. In this regard, the generally low velocity of groundwater movement, which tends to inhibit mixing and diffusion in a groundwater basin, must be taken into account. Water movement through soils is laminar rather than the typically turbulent flow found in surface waters; therefore, dilution of the recharged water by the native groundwater may be significantly reduced. (12, 16)

The different methods of recharge (percolation or injection) require a different set of quality criteria. This results because the treatment provided by the soil in the percolation system may not be available to direct aquifer injection programs. In addition, injection systems require a much higher quality of water to meet hydraulic requirements than do spreading basin programs. Naturally, in all situations, the greater the degree of treatment given to wastewater, the more efficient will be the infiltration, diffusion, and injection capabilities of the recharge water. (1) If recharge is to remain economical, the charging capacity of individual wells and spreading basins must be maintained.

In all cases of direct injection (Long Island, New York, Orange County, California, and Palo Alto, California), it is anticipated that under full scale operation, the recharge water will meet drinking water standards, and at Orange County it is stipulated by the Water Quality Control Board that the treated effluent be diluted 50:50 with a fresh water source to achieve a TDS concentration of 550 mg/l. Naturally, all these operations require extensive tertiary treatment to obtain desired pollutant removals.

REPORTED RECHARGE WATER QUALITY

The following concentrations reported by the case study programs give a general indication of the quality provided or anticipated for successful injection well recharge (note that hydraulic characteristics of the aquifer can force significant changes in these criteria): BOD $\leq$ 5 mg/l, SS $\leq$ 0.5 mg/l, Fe $\leq$ 0.6 mg/l, PO_4 $\leq$ 1 mg/l, turbidity $\leq$ 0.4 mg/l as SiO_2, and coliforms $\leq$ 2.2/100 ml.

For successful operation, recharge by percolation does not require as high a quality of water as injection systems. Case study projects reported no problems of surface clogging, significantly reduced infiltration rates, or degradation of groundwater (within the constraints of their testing programs) when good quality secondary effluent was used for spreading (BOD and SS concentrations less than 20 mg/l).

CRITICAL QUALITY PARAMETERS

At present, the most significant detectable long term hazard to groundwater quality caused by recharge activities is the buildup of dissolved salts. The U.S. Public Health Service (USPHS) has established, in a 22-city survey, that each use of water adds approximately 300 mg/l of TDS to the supply. Over the long term, the gradual increase of TDS in the groundwater may require the use of in-plant demineralization or blending with fresh water supplies to maintain low TDS in the aquifers.

The newest concern in regard to contamination of groundwater basins through effluent recharge is residual organics.

A group of scientists, particularly water quality specialists in the field of water supply, wastewater disposal, and public health, are concerned about residual organics and sources of domestic wastewater. Questions about the fate of residual organics (present in treated effluent) within the soil-aquifer system have not been answered (i.e., synergistic effects between organics or other groundwater and soil constituents, conversion of safe organics to hazardous compounds in the soil, etc.).(10)

Other wastewater constituents which can potentially create problems in groundwater systems include heavy metals and detergents. As with dissolved salts, these contaminants can accumulate in the aquifers, often rendering a groundwater system unusable. As mentioned previously, soils of higher clay content and ion exchange capacity will tend to remove much higher percentages of metals than will the sandy soils, which are prevalent at most percolation recharge sites because of their high infiltration rates. Thus, the extent of potential contamination depends to some extent on the soil characteristics.

It should be emphasized that each potential recharge site must be thoroughly studied to determine the acceptable limits of water quality based on the parameters discussed above. The peculiarities of a groundwater system may require more stringent quality for certain wastewater constituents.

SECTION V

DESCRIPTION OF CURRENT PRACTICES

INVENTORY OF RECHARGE SITES

Table 1 provides a summary of the groundwater recharge sites using municipal wastewater that are operational or under construction in the United States.

As shown, six of the programs include groundwater basin replenishment as one of the purposes of recharge; six involve establishment of saltwater intrusion barriers; and three also recharge to provide further land treatment before extraction for reuse.

All but three of the sites are located in the arid southwestern area of the country where low precipitation patterns force heavy reliance on groundwater supplies. Increasing populations create critical overdraft situations that can be alleviated in part by recharge of treated wastewater either for direct basin replenishment for unrestricted reuse, or for extraction and non-potable reuse.

Two of the recharge sites are located in temperate climates at Long Island and Palo Alto. Both areas, however, are heavily dependent on groundwater supplies and initiated recharge programs to halt seawater intrusion into their aquifers. The Long Island operation has since altered their emphasis from coastal saltwater intrusion barriers to inland basin replenishment.

Economic conditions on St. Croix in the Virgin Islands lend themselves to the recharge of wastewater, as potable water is scarce and very expensive. At least two-thirds of the islands' domestic supply is derived from distillation of seawater.

PRELIMINARY TESTING

All the recharge operations conducted some type of preliminary testing before commencing full scale operations.

Site testing at the percolation recharge sites generally included: Soil boring tests to ascertain soil profiles;

Table 2. INVENTORY OF RECHARGE OPERATIONS

Location	Managing agency	Purpose of recharge	MGD
Camp Pendleton, CA	U.S. Marine Corp.	. Groundwater replenishment . Salt water barrier	4
Hemet, CA	Eastern Municipal Water District	. Groundwater replenishment	2
Long Island, NY	Nassau County Department of Public Works - U.S. Geological Survey	. Groundwater replenishment . Salt water barrier	0.5
Oceanside, CA	Water and Sewer Dept.	. Treatment for reuse	6(3)
Orange County, CA	Orange County Water District	. Groundwater replenishment . Salt water barrier	15(1)
Palo Alto, CA	Santa Clara Valley Water District	. Salt water barrier . Treatment for reuse	2(2)
Phoenix, AZ	U.S. Water Conservation Laboratory	. Treatment for reuse	15(1)
San Clemente, CA	City of San Clemente	. Salt water barrier	2
St. Croix, V.I.	Govt. of the V.I.	. Groundwater replenishment . Salt water barrier	0.5
Whittier, CA	L.A. County Flood Control District	. Groundwater replenishment	25

(1) Full scale facility on line in 1975.
(2) Full scale facility on line in 1976.
(3) Present system temporarily provides 1 MGD for groundwater replenishment. New 6 MGD program operational 1975.

and percolation tests to aid in determining optimum recharge rates, system capacity, and clogging characteristics. Soil profiles are important for locating impermeable clay layers that can impede vertical migration and reduce infiltration rates or force the water in horizontal directions. These profiles also show the size distribution of material with depth so that the experimenter can determine where the formation is likely to exhibit clogging, whether there is a danger of the water table rising too close to the bottom of the basins, whether there is likely to be significant cation exchange phenomena due to the presence of clay, and other important considerations.

Extensive percolation tests performed with representative treated effluent are advantageous in that they provide information as to initial infiltration rates, long term hydraulic loading rates, the necessary area of the spreading basins, and what types of problems with clogging will arise.

Soils comprised of gravels, coarse and medium sand, and sandy loam offered the best results for percolation due to their high percolation rates and reduced surface clogging. Percolation tests and operational results at case study locations showed infiltration rates ranging from 1 to 10 ft/day.

Preliminary testing at sites utilizing wells for injection or extraction was more extensive than that for percolation programs. The Santa Clara Valley Water District's preliminary test program at Palo Alto can serve as an example of an in-depth study. Test holes were drilled initially with samples taken every few feet to obtain accurate information as to subsurface characteristics. After each hole was drilled, geophysical logging was performed in the well to verify the written descriptive log and to gather data on water quality, permeability of formations, and variations in material type (especially the presence of clay formations).

Observation wells were then drilled to monitor changes in water level and to collect water quality samples during subsequent testing. A test injection/extraction well was drilled and recharge tests with fresh water initiated. The main purposes of these recharge/extraction tests were to determine the maximum rates of recharge into the aquifers, the changes of these rates with time, and the changes in water quality with movement through the formation. The important parameters were transmissivity (gpm/ft), which represent the rate of yield (gpm) per foot of drawdown under extraction conditions, and the rate of injection (gpm) per foot of head during injection. Higher aquifer transmissivity denotes a more porous or permeable formation. Typical values at Palo Alto ranged from 3,000 gpd/ft to 12,000 gpd/ft. Once all the aquifer and recharge characteristics were determined, a computer simulation of the system was devised to calculate optimum locations for the series of injection and extraction wells.

This basically concluded the test program at Palo Alto. One possible disadvantage was the fact that recharge tests were all run with fresh water. Whenever possible, the optimal choice would be to use the same or nearly identical water source to that to be used under full scale operation. This was done at Long Island, New York, where the test program included a pilot tertiary treatment plant that provided treated effluent to the test well complex.

TREATMENT PRIOR TO RECHARGE

The degree of treatment provided before recharge depends on the purpose of the program and the method of recharge.

Three of the coastal sites (Long Island, Palo Alto, and Orange County) are faced with saltwater intrusion problems and are either designing, constructing, or operating tertiary treatment plants with well injection effluent systems to create salinity intrusion barriers. Due to the nature of the subsurface materials, a high quality water is needed to prevent clogging of the pore spaces in the aquifer and to assure that no degradation of ambient groundwater quality occurs. These injection systems require extensive tertiary treatment prior to recharge to reduce solids, phosphorous, nitrogen, iron, other precipitate-forming compounds, entrained gases, bacteria, viruses, and other contaminants. See Appendix A case studies for a more detailed discussion.

The other seven programs employ percolation to recharge aquifers for groundwater replenishment, saltwater barriers, and/or treatment before reuse. Five of these operations rely on percolation through depths of soil to yield the tertiary treatment that injection systems must provide in-plant. These sites operate directly with secondary effluent, although three of the five provide final polishing ponds to reduce solids and prevent surface clogging during spreading. Two percolation operations, San Clemente, California, and St. Croix, Virgin Islands, provide dual media filtration as a tertiary treatment step prior to spreading.

Table 3 provides a summary of treatment systems and typical effluent quality characteristics.

Table 3. TREATMENT SYSTEMS AND EFFLUENT QUALITY CHARACTERISTICS

Location	Treatment	Effluent Quality(2)						
		BOD	SS	Total N	Total P	Coliform 100/ml	Fe	TDS
Camp Pendleton, CA	Secondary (T.F.)	16	10	11	2.8	—	0.8	790
Hemet, CA	Secondary (A.S)	20	18	49	—	1.8 x 10^6	—	676
Long Island, NY	Tertiary - chem. clar. - filtration - carbon adsorp. - chlorination	5	0.5	35	0.4	<1	0.4	394
Oceanside, CA	Secondary (A.S.)	6	10	23	31	25	0.07	1,200
Orange County, CA (1)	Tertiary - chem. clar. - ammonia strip. - recarb. - filtration - carbon adsorp. - chlorination	<1	<1	10	<1	<1	0.6	1,100
Palo Alto, CA (1)	Tertiary - chem. clar. - ammonia strip. - recarb. - filtration - carbon adsorp. - chlorination	1	<1	10	<1	<2.2	0.2	670

(1) Anticipated characteristics

A.S. - activated sludge
T.F. - trickling filter

Table 3 (continued). TREATMENT SYSTEMS AND EFFLUENT QUALITY CHARACTERISTICS

Location	Treatment	Effluent Quality (2) BOD	SS	Total N	Total P	Coli/ 100/ml	Fe	TDS
Phoenix, AZ	Secondary (A.S.)	15	50	36	15	10^6	—	1,100
San Clemente, CA	Tertiary - filtration	4	3	—	20	< 2.2	—	1,400
St. Croix, V.I.	Tertiary - chem. coag. - filtration	12	—	—	—	—	—	1,000
Whittier, CA	Secondary (A.S.)	8	12	27	6	196	0.20	640

(2) Expressed in mg/l except for the coliform values which represent per 100 ml.

As would be expected, the three extensive tertiary operations provide a very high quality effluent with BOD's below 5 mg/l, SS less than 1 mg/l, coliform less than 2 per 100 ml, and other low contaminant concentrations. Note that the Orange County effluent will be mixed 50-50 with desalinated water before injection which will roughly halve all contaminant concentrations.

With the exception of high suspended solids in the Phoenix wastewater, the secondary effluents used for percolation recharge were of good to excellent quality for that degree of treatment with all BOD and SS concentrations under 20 mg/l. Nutrient values were typical of secondary effluent.

TDS concentrations were quite high at all locations except Long Island, indicating that possibly the aquifers were intruded or otherwise high in salts; that the recharge water was to be extracted; that the effluent was mixed with low TDS sources before recharge; or that some form of demineralization would ultimately be necessary to prevent TDS buildup in the groundwater basin. Table 4 compares the TDS concentration of the recharge water with the existing TDS level of the receiving groundwater aquifer.

The individual case study reports provide detailed summaries of effluent characteristics.

Methods of Recharge

There are two basic methods of groundwater recharge utilized by the surveyed sites. The simplest and most widely used consists of conveying the treated effluent to shallow spreading basins and allowing the water to percolate through the soil to the groundwater. The other method consists of conveying the effluent to a well field and injecting the water directly into the aquifer for basin replenishment or to form a pressure mound which can be effective in retarding salt water instrusion. Figure 2 shows a basic diagram of the salt water intrusion problem. Intrusion is usually accelerated by drawdown of the water table and lowering of the potentiometric head in the fresh water aquifer due to extraction for potable supplies. The recharge pressure mound also shown in Figure 2 serves as a pressure barrier against the intruding seawater.

Table 5 provides a summary of facilities and management practices for the seven high rate percolation recharge sites. The programs using percolation had varying numbers of basins from one to 20 acres each. Basin berms were roughly three to six feet high, and flooding depths ranged

Table 4. COMPARISON OF TDS IN RECHARGE WATER AND RECEIVING GROUNDWATER

Location	TDS mg/l	
	Recharge Water	Aquifer
Camp Pendleton, CA	790	680
Hemet, CA	700	500-900
Long Island, NY	300	50
Oceanside, CA	1,280 (1) (4)	
Orange County, CA	550 (2)	520
Palo Alto, CA	850 (4)	4,500-6,000 (3)
Phoenix, AR	1,100 (4)	800
San Clemente, CA	1,100	400-850
St. Croix, V.I.	1,000 (5)	1,200
Whittier, CA	640	250-850

(1) High concentration due to: use of high TDS Colorado River water for supply, salt water infiltration into sewer lines, and high evaporation rates from holding lagoons.

(2) After blending 1:1 with desalinated water.

(3) Salt water intruded aquifer.

(4) All recharged water to be extracted with virtually no mixing with natural groundwater.

(5) High concentration due in part to limited use of saltwater for toilet flushing.

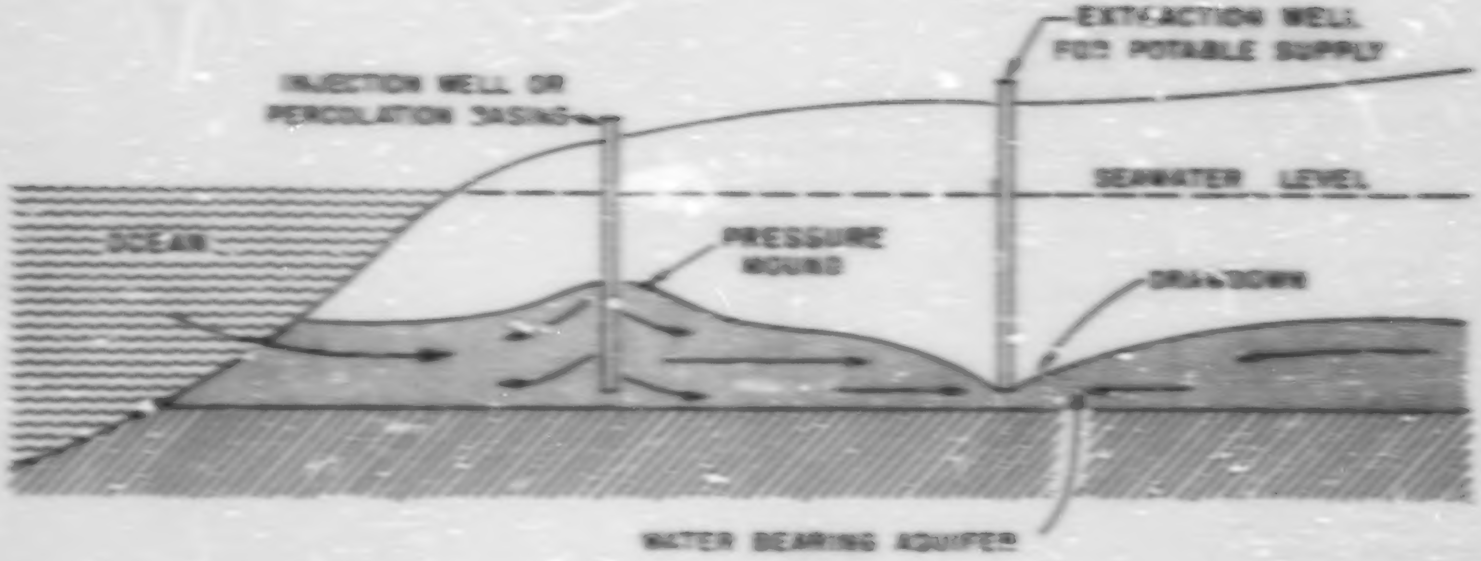
INJECTION WELL OR
PERCOLATION BASINS
EXTRACTION WELL
FOR POTABLE SUPPLY
SEAWATER LEVEL
OCEAN
PRESSURE
MOUND
DRAWDOWN
WATER BEARING AQUIFER

FIGURE 2
BASIC DIAGRAM OF
SALTWATER INTRUSION
INTO FRESH WATER AQUIFER

Table 5. SUMMARY OF FACILITIES AND MANAGEMENT PRACTICES FOR PERCOLATION RECHARGE

Location	Loading Rate mg/acre/yr	Ave. Percolation Rate ft/day	Flood Sch.	Soil Type	Spreading Area Maintenance Operations
Camp Pendleton, CA	N/A	8	. As water becomes available	coarse sand	. berm redevelopment . remove surface solids every other year
Hemet, CA	29	2.5	. Fill 1 day (2.5'depth) . Drain 2 days . Dry 1 day	medium & coarse sand	. periodic rototilling of basins
Oceanside, CA	47	4.5	. Fill to 3' depth . Drain & dry . Refill	coarse sand	. basins scarified periodically
Phoenix, AZ	137	2.5	. Fill 10 days . Dry 14 days	. loamy sand surface . coarse sand and gravel	. closely maintain flooding schedule . periodic scarifying
San Clemente, CA	163	5-10	Continuous	coarse sand and gravel	. none

Table 5 (continued). SUMMARY OF FACILITIES AND MANAGEMENT PRACTICES FOR PERCOLATION RECHARGE

Location	Loading Rate mg/acre/yr	Ave. Percolation Rate ft/day	Flood Sch.	Soil type	Spreading Area Maintenance Operations
St. Croix, V.I.	36	1-2	• Fill 10 days • Dry 30 days	silt, sand and clay	—
Whittier, CA	46	5-13	. Fill 6 days (4" depth) . Drain 6 days . Dry 6 days	sandy loam	. basins scarified periodically

from one to four feet. Successful high rate percolation requires porous soil. All the sites surveyed had good percolation rates ranging from roughly one foot per day at Phoenix to over ten feet per day at Camp Pendleton. These infiltration rates are much higher than evaporation rates, and thus the salt content is not concentrated during flooding. Soil composition was generally of sand, loam, and gravel composition with clay stratas at varying depths. Most sites maintain bare earth bottoms in their basins, but at Whittier Narrows natural vegetation was not removed as its presence increased performance.

Management techniques varied with location. All sites except San Clemente, which has very high percolation rates, operated on some type of flooding-drying cycle to reduce clogging and retain high percolation rates. Hemet, California, operated a short (four day) cycle to reduce algae growth that had been stimulated by long flooding periods and significant nutrient content in the wastes.

The Flushing Meadows project at Phoenix adopted a longer flooding-drying technique to achieve maximum removals of nitrogen. By controlling the aerobic and anaerobic conditions in the soil, optimum nitrification-denitrification can be realized with nitrogen removals as high as 80 percent. Some sacrifice in maximum volume percolated has to be made due to the controlled flooding techniques necessary to achieve significant nitrogen removals.

Operation and maintenance requirements are very minimal for percolation recharge systems. The entire operation is simple and only requires basic allocation of water to the basins and periodic tilling of pond bottoms to break up solids.

Recharge systems incorporating injection are naturally more sophisticated and complicated than spreading-percolation facilities. Table 6 summarizes basic characteristics of the injection well systems. None of the three systems had operated at full scale operation at the time of the study. Anticipated startup dates are: early 1975 - Orange County, 1976 - Palo Alto, and 1977 or later for Long Island. All three sites have run pilot studies to determine the characteristics of the aquifers, spacing of barrier wells, injection techniques, etc.

Both the Long Island and Palo Alto systems achieve recharge by injection pumps at each well. Orange County, however, maintains one force main at 50 psi with three large effluent pumps supplying the head to all 23 wells.

Table 6. CHARACTERISTICS OF INJECTION RECHARGE SYSTEMS

Location	No. Injection Wells	Ave. Injection Depth (ft)	Well Dia. (in.)	Max. Pumping Rate per Well (gpm)	Max. Injection Pressure (psi)
Long Island, NY (1)	1	450	18	400	100
Orange County, CA (2)	23	96, 150, 250, 340	6	900	50
Palo Alto, CA (3)	9	45	6	250	20

(1) Pilot operation only
(2) 1975 start-up
(3) 1976 start-up

Three of the 10 case study programs plan to extract the recharged water for reuse and to minimize mixing of the treated effluent with native groundwater supplies. These programs, Oceanside and Palo Alto, CA, and Phoenix, AZ, are designing extraction systems such that all gradients in the local groundwater zone will be directed toward the extraction wells to virtually eliminate migration of recharged waters out into the aquifers. By recovering the recharged waters, these programs will avoid having to meet the quality requirements or health considerations that would be asked of a straight basin replenishment program.

At Phoenix, the three extraction wells will be located in the middle of the spreading basins and will each pump up to 4,000 gpm to a local irrigation district. At both Palo Alto and Oceanside, extraction will occur downstream from the recharge point (1/2 mile at Oceanside, 1,000 ft at Palo Alto) to provide further soil treatment before reuse.

The pilot well at Long Island provided both injection and extraction capabilities. Extraction was for purposes of regeneration or backwashing to remove solids and precipitate from the clogged aquifer. Due to the heavy clogging phenomenon, initially extracted water was highly contaminated with solids, precipitates of iron and phosphate, and bacteria. Authorities do not anticipate the use of extraction wells under full scale operation.

The Orange County program will utilize both injection and extraction wells to form a hydraulic pressure barrier against intrusion. As shown in Figure A-6 of the case study report, injected water will not be recovered as at Palo Alto and Phoenix, but will serve both to replenish the four fresh water aquifers and to form the seawater barrier. The existing line of 7 extraction wells located two miles seaward from the injection points will continue to pump out intruding salt water and return it to the ocean.

Of the 10 recharge operations, seven used only treated effluent in their systems. The other three (Camp Pendleton, Orange County, and Whittier Narrows) used a mixture of effluent and other fresh water sources to make up their recharge supply. Camp Pendleton and Whittier Narrows used effluent continually and mixed in natural runoff when available. Orange County will mix its effluent 50:50 with desalted water to meet their TDS restriction.

Monitoring and Safeguards

Extensive monitoring and safeguard measures were not practiced by most of the percolation type recharge operations because they could rely on the soil to provide significant treatment and thus ensure a high quality water entering the groundwater basins, and also because of the significant difficulties in tracing the movement of the recharge water in the subsurface system and in obtaining representative samples. Monitoring usually consisted of the standard effluent tests (BOD, SS, coliform, etc.) conducted daily and other typical tests run periodically. Volume of effluent diverted to flooding basins was often monitored with flow recorders to assure proper flooding depths and periods.

The case study reports showed that supply wells, extracting from basins replenished to some extent by treated wastewater, were monitored periodically for signs of contamination due to the use of treated wastewater for recharge. Except for minor increases in TDS concentrations, no degradation of native groundwater quality was reported. It is important to note that none of the sites monitored potentially hazardous trace pollutants such as pesticides, trace organics, and viruses.

In addition to monitoring potable supply wells, two of the percolation programs (Hemet and Phoenix) operated networks of observation wells to monitor groundwater levels and quality. At Phoenix, the effluent quality was analyzed before recharge and after extraction to determine pollutant removal efficiencies of their various soil systems and operation techniques. In a similar fashion, sampling pans were constructed under small test basins at Whittier Narrows to measure the effect on water quality of percolation through varying depths of soil.

Due to the high quality requirements and low tolerance of injection systems, treatment plant and well operations were more closely monitored than in the percolation programs. This generally consisted of more extensive and frequent effluent monitoring and closer operational control to ensure that treatment plant upsets were minimized and that poor quality effluent was not sent to the well.

To safeguard injection well operation, storage capacity for the final effluent was provided so that treatment plant shutdowns would not affect injection. This storage also provided the capability to mix the effluent with other water sources if desired. All the injection-type recharge programs include a by-pass safeguard so that poor quality effluent due to plant upset or breakdown can be discharged without entering the injection well system and causing problems there.

At Long Island, the recharged effluent was extracted and analyzed to determine the dispersion patterns of pollutants in the aquifer and the causes of the severe clogging occurrences. The problem was traced to precipitates of phosphate and iron, and residual particulate matter clogging fine pore spaces. The Long Island case study fully delineates dispersion patterns and these operational problems.

Problems Encountered

One of the advantages of percolation recharge systems is the virtual absence of equipment and instrumentation. The simplicity of the facilities greatly reduces the number and degree of operational problems.

The most prevalent setback is clogging of the surface soil layer, thus reducing infiltration rates. The clogging is due to the accumulation of solids from the effluent and algae growth stimulated by nutrients in the wastewater. This problem can be eliminated for the most part by an alternate flooding-drying schedule with intermittent scarification or rototilling of the pond bottom. This cyclic schedule also serves to interrupt the life cycles of mosquitoes and other aquaphilic insects.

Both Whittier Narrows and Hemet noted difficulties in monitoring the movement of the effluent once it had percolated. Mixing with native groundwater and horizontal deflection due to impermeable clay layers were cited as the causes of the problems.

Problems are more inherent in injection recharge systems due to the sophistication of both the tertiary treatment plant and the injection well facilities. The problems associated with extensive tertiary treatment have been well-documented elsewhere. Of the five tertiary systems included in this study, only two were operational -- Long Island and San Clemente. The only difficulties reported were at Long Island and included: frequent breakdown of the activated carbon regeneration furnace; anaerobic bacteria in the carbon towers converting iron to soluble forms that precipitated during injection and clogged the well; and surges of suspended solids in the effluent immediately following mixed media filter backwash. The latter two problems were successfully eliminated.

The injection well system can also present operational problems depending upon the quality characteristics of the effluent and the hydraulic characteristics of the aquifer.

Pilot well programs at Orange County and Palo Alto were carried out with a minimum of setbacks. The experience with the pilot deep well injection with tertiary effluent at Bay Park, Long Island, was not as fortunate. Due to the very small pore spaces in the deep aquifer, clogging in the immediate injection area was a continual problem. Clogging occurred whenever the effluent turbidity was greater than 0.3 JTU, when PO_4 concentration rose above 1.0 mg/l, when Fe increased over 0.3 mg/l, or when surges of higher solids concentrations were injected. This test proved that recharge water quality must be rigidly controlled and that injection of treated effluent into aquifers with small pore spaces was difficult even with very high quality water.

The difficulty in controlling the recharge-extraction process to ensure that little recharged water enters the virgin groundwater (if that is not desired) can be overcome by proper system operation and design as planned at Phoenix, Palo Alto, and Oceanside. Explained in greater detail in the Phoenix case study report (Appendix A), the method basically involves establishing a slight gradient in the groundwater basin toward the extraction point.

The problem of native groundwater contamination by recharged effluent has not been reported to date at the 10 sites surveyed. Water extracted from basins being replenished with effluent or a mixture of sources has not shown any measurable degradation and program coordinators are confident that their recharge operations are not contaminating the aquifers, except where high recharge water TDS is a potential long term problem. Health authorities, on the other hand, argue that the potential still exists for contamination by effluent recharge until research proves not only that the soil effectively removes trace organics over the long term, but that satisfactory monitoring and analysis techniques have been developed to prove it.

SECTION V

ANALYSIS OF RECHARGE ECONOMICS

The costs for recharge were analyzed for each of the case study sites. Included in this analysis were the costs associated with recharge only, not treatment, unless recharge required specific treatment units beyond normal secondary facilities (i.e., tertiary treatment for well injection). In cases where recharged water was extracted for reuse (Oceanside, Palo Alto, and Phoenix), the costs of extraction were also included.

Table 7 summarizes estimated costs for the recharge operations. Two of the tertiary treatment/injection recharge programs (Palo Alto, California, and Orange County, California) received substantial state and federal grant monies that covered a large percentage of the total project capital cost. Total project costs, including grants, are shown in parentheses along with the costs paid only by the host water districts. As would be expected, there is generally a significant difference in cost between the percolation type and the injection type operation because of the expensive tertiary treatment and well systems necessary for the latter.

The total costs for percolation recharge ranged from $8/mg at Phoenix to $147/mg at Oceanside with an average of $43/mg for all seven sites. Costs appear to be basically a function of distance and elevation difference between treatment plant and spreading basins. Piping and pumping, along with land acquisition, are the major costs.

The lowest cost system (Phoenix at $8/mg) was situated adjacent to the treatment plant, and effluent was gravity fed through gate valves directly to the spreading basins; thus there are no piping or pumping costs except for the extraction process that represents the major portion of the total cost. Oceanside, on the other hand, was anticipating a cost of over $1,600,000 for over eight miles of large diameter piping and a pump station. Land costs were also high for acquisition of extensive holding pond spreading

Table 7. ESTIMATED TOTAL COSTS OF RECHARGE OPERATIONS(1) (1972$)

$/MILLION GALLON

Location	MGD Recharged	Type of Treatment	Type of Recharge(3)	Capital Cost(4)	O & M Cost	Total Cost
Camp Pendleton, CA	4	Sec.	P	7	8	15
Hemet, CA	2	Sec.	P	9	21	30
Long Island, NY	intermittent	Tert.	I	—	320	—
Oceanside, CA	6	Sec.	P,E	111	36	147
Orange County, CA(2)	15	Tert.	I	94(253)	574	670(827)
Palo Alto, CA	3	Tert.	I,E	30(176)	137	167(313)
Phoenix, AZ	15	Sec.	P,E	3	5	8
San Clemente, CA	2	Tert.	P	37	5	42
St. Croix, V.I.	0.5	Tert.	P	—	—	—
Whittier, CA	25	Sec.	P	8	7	15

(1) Excluding revenues from sale of water
(2) Cost includes both the wastewater treatment portion of the project and the R & D desalination activities
(3) P - percolation
I - well injection
E - immediate extraction for reuse
(4) Costs in parenthesis represent total project costs including all state and federal grant monies for those projects receiving such funding; the other cost figure for these programs is that portion of the cost paid by host agency

basins and extraction areas totalling 150 acres. Note that Phoenix, with 2-1/2 times the flow of Oceanside, used less than 1/3 the land for recharge. The capital costs at San Clemente were significantly increased by nearly five miles of pipeline and two high power pump stations along with two dual media filters to provide tertiary polishing.

Total costs for the three tertiary treatment/injection recharge systems ranged from $313/mg anticipated at Palo Alto ($167/mg of which will be paid by the SCVWD) to over $800/mg reported by the operation at Orange County. Costs reported by the latter are inflated substantially over what they will be under full scale operation due to the unusually high operation and maintenance costs associated with R & D work on the desalting module. Costs at Orange County can be broken down as follows: $240/mg for the advanced wastewater treatment plant, $2,722/mg for the desalination plant, and $10/mg fur thw distribution and well system.

It is important to note that both the Santa Clara Valley Water District (Palo Alto) and the ORange County Water District will have to pay only a portion of the total cost. The Santa Clara Valley Water District is responsible for 12-1/2 percent of the total capital cost and the Orange County Water District needs to contribute only 20 percent of the advanced wastewater treatment plant capital cost, 42 percent of the desalination facility costs, and 60 percent of recharge facilities capital cost. The remaining funding is provided by state and federal grants.

In contrast to the percolation programs, the major cost on a yearly basis for the injection systems is operation and maintenancu of the extensive tertiary treatment plants. For the two full scale injection systems, O and M costs represent roughly 40-70 percent of the total annual cost with capital recovery costs for treatment and injection facilities (amortized at 5.5 percent for 25 years) constituting the remainder.

Analysis of the economics of recharge shows that percolation is a very inexpensive method of replenishing groundwater basins. It can provide treatment prior to reuse and/or protection against salt water intrusinn. Costs are exceptionally low if recharge areas can be located in close proximity to the treatment plant.

If injection is necessary to repel saltwater instrusion due to lack of available land or proper soil features for percolation, the costs of the program will be significant.

These costs, however, can be deferred to some extent by extraction and sale of the recharged water for reuse and by the elimination or delay of the development of new sources due to the protection and/or replenishment of present groundwater supplies.

Only two of the sites (Palo Alto and Phoenix) were planning to obtain direct revenue from the sale of water extracted after recharge. A significant portion of the recharge program cost can be recovered as Palo Alto plans to sell roughly 2 mgd at $130/mg and Phoenix will sell approximately 15 mgd at $5/mg.

SECTION VII

APPENDICES

APPENDIX A

FIELD INVESTIGATION REPORTS

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UNITED STATE MARINE CORPS (CAMP PENDLETON, CALIFORNIA)

Introduction

The USMC base at Camp Pendleton has been operating an extensive water resource management program since 1943. The main purpose of this program is to allocate, protect, and replenish the groundwater resource to ensure that quality is not degraded nor volumes depleted over the long-term. The base has always relied solely on groundwater for its water supply and hopes to avoid any reliance on external sources in the future by proper management of their groundwater basins. The basins are continually recharged with reclaimed sewage, stored surface runoff, and local precipitation (13 in/yr) when available. The volume of reclaimed effluent recharged is equivalent to roughly 2/3 of the total volume extracted for potable use.

Domestic Treatment

The base, with a total population of 35,000, presently operates nine small sewage treatment plants that treat a total of 4 MGD.

By October, 1975, all the plants will have been updated to provide primary and biological secondary (trickling filter) treatment. All effluent is heavily chlorinated and a portion receives some degree of tertiary treatment in oxidation ponds, all of which will be mechanically aerated by 1976. Table A-1 summarizes typical effluent characteristics from one of the secondary plants.

Recharge Program

Potable water for Camp Pendleton is supplied by extracting deep groundwater from basins of four of the five stream systems on the base. These basins are recharged continuously with reclaimed effluent, surface runoff, and local precipitation. Water allocations are constrained within the safe perennial yields of the basins. This ensures that water may be extracted over a long term without depleting the storage to the point where seawater intrusion occurs, chemical deterioration of the groundwater results, or extraction becomes economically infeasible.

Since the four productive basin areas are basically similar in physical characteristics and recharge operations, the remainder of this section will provide a more detailed description of only one of the basins.

Table A-1. TYPICAL SECONDARY EFFLUENT CHARACTERISTICS AT CAMP PENDLETON

Constituent	Concentration mg/l	Constituent	Concentration mg/l
BOD	10	SO_4	148
SS	10	Cl	184
TDS	790	Total N	11
Total hardness as $CaCO_3$	184	B	0.4
Ca	48	Total Fe	0.0
Mg	16	Mn	0.14
Na	144	ABS	0.44
K	38	Total P	2.0

The Santa Margarita River, with a watershed area of approximately 750 square miles and groundwater basins with 76,000 acre-ft capacity, is the largest and most important of the streams discharging into the ocean within the confines of Camp Pendleton. The lower portion of the river system consists of an alluvial valley, and coastal basin of 4,500 acres that have been subdivided in three interconnected basins for recharge purposes.

Recharge of the basin is accomplished by utilizing various water conservation techniques: on-channel water spreading structures, off-channel water spreading structures, recycling of sewage effluents, phreatophyte control, and construction of erosion control structures.

Figure A-1 shows a schematic diagram of the Santa Margarita recharge facilities. During the rainy season, surface flow in the Santa Margarita River is diverted by a rock weir to either Lake O'Neill or off-channel spreading basins. All the basins are composed of coarse sand with very high infiltration rates of up to 5 in/hr. The 1,320 acre-ft capacity lake is constantly fed by 1.4 MGD from the town of Fallbrook's sewage treatment plant, and may also receive effluent from Pendleton's Plant No. 1, if so desired. The lake serves as a storage reservoir during the rainy season with impounded water being released to on-channel spreading basins during the dry summer and early fall months.

Nine on-channel water spreading structures are situated below the rock weir diversion to Lake O'Neill. They are comprised of river sand and are constructed similar to levees with spillways. During heavy runoff periods, surface flow spills over the rock weir diversion and continues down the Santa Margarita River filling and spilling each on-channel structure successively. These structures are not designed to withstand major flows.

Effluents from five sewage treatment plants are utilized to recharge the basins and to maintain a salt water intrusion barrier. Figure A-1 shows the treatment plants and their discharge points.

In order to further conserve the groundwater source, phreatophytes are physically removed from Lake O'Neill and the spreading basins to reduce the loss of water to these plants. Authorities estimate that for every acre of phreatophytes cleared, two acre-feet per year of groundwater is saved.

Program monitoring consists of weekly water level observations at key wells throughout the basins, as well as periodic

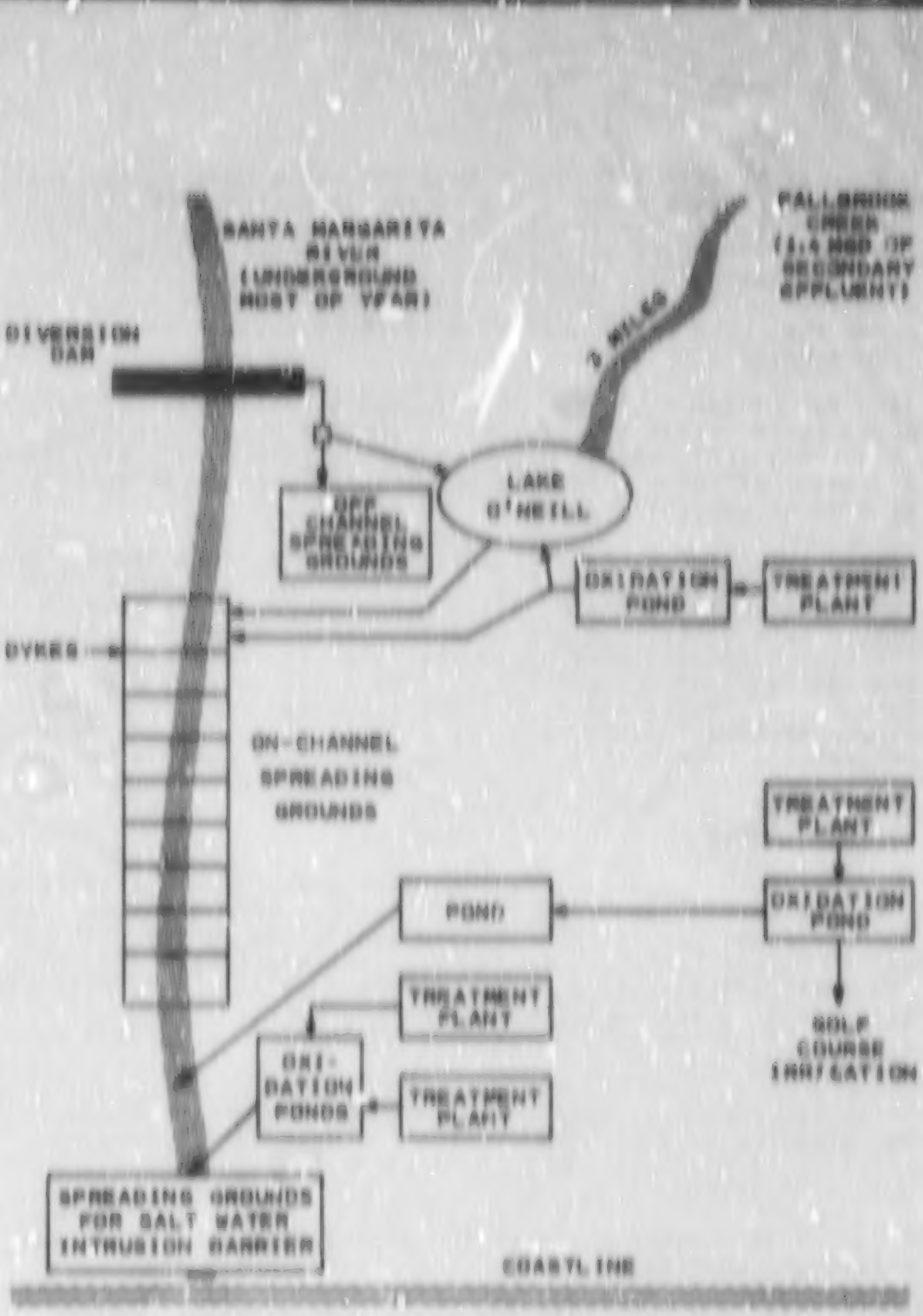
SANTA MARGARITA
RIVER
(UNDERGROUND
MOST OF YEAR)
FALLBROOK
CREEK
(1.4 MGD OF
SECONDARY
EFFLUENT)
3 MILES
DIVERSION
DAM
LAKE
O'NEILL
OFF
CHANNEL
SPREADING
GROUNDS
OXIDATION
POND
TREATMENT
PLANT
DYKES
ON-CHANNEL
SPREADING
GROUNDS
TREATMENT
PLANT
POND
OXIDATION
POND
GOLF
COURSE
IRRIGATION
TREATMENT
PLANT
OXI-
DATION
PONDS
TREATMENT
PLANT
SPREADING GROUNDS
FOR SALT WATER
INTRUSION BARRIER
COASTLINE

FIGURE A-1
SCHEMATIC DIAGRAM OF SANTA MARGARITA
RIVER BASIN RECHARGE FACILITIES,
CAMP PENDLETON, CA.

sampling of groundwater (quarterly) and incoming surface water quality (monthly) in all the basins. Data from these observations and tests is used to allocate water for recharge and to schedule extraction so as to maintain the highest possible quality and safe perennial yields within the aquifers.

Table A-2 summarizes typical groundwater quality. The high TDS concentration is due basically to added salts from upstream users and to the Colorado River Water source utilized by these towns that eventually finds its way into Camp Pendleton basins. To the present, there have been no instances of virus, bacteria or other contamination of the potable water supply due to the rechargw with treated wastewater and natural supplies.

Twelve wells are used in the Santa Margarita basin to extract the potable water supply for the base. These wells are located in the Upper Valley and Chappo Valley Basins of the system with the lower Ysidora Basin used only for salt water intrusion prevention. The sixteen inch diameter wells range from 150-300 ft deep and are capable of pumping up to 1,400 GPM. The upper 80 feet of each well is covered with a sanitary seal and the deepest 60 feet provided with perforations. Water extracted is heavily chlorinated at the well sites before being pumped to reservoirs. It is chlorinated again prior to entering the distribution system.

It is important to note that although the recharged water enters the potable aquifer, it basically forms a layer at the top of the groundwater basin and has little chance to mix with water in the deeper potable zone (150-300ft). Dur- the rainy season, natural precipitation and runoff tend to carry the upper zone of the aquifer (containing most of the treated effluent) into the ocean. The actual amount of recharged water reaching the potable zone and being pumped out for domestic reuse is estimated to be quite low.

Economics

Costs for the recharge system at Camp Pendleton are minimal Annual operation and maintenance costs are $12,000 which covers the costs of maintaining the berms, diversion channels, etc., and of removing a thin silt layer from the percolation basins every other year. Annual capital recovery costs are estimated at $10,000 per year for construction of basins, piping, flow meters, and pumps. Thus, the total cost for the recharge operation breaks down to $15/MG (1972 $).

Table A-2. TYPICAL GROUNDWATER QUALITY AT A 200 FOOT DEPTH AT CAMP PENDLETON

Constituent	Concentration mg/l	Constituent	Concentration mg/l
TDS	600	SiO_2	18
NO_3	0.01	F^-	0.64
PO_4^{-3}	0.11	B	0.11
SO_4	138	Total Fe	0.05
Cl	158	Mg	13
K	2.9	Total Hardness	240

The base is realizing a substantial savings due to its water recharge management program. The base currently uses over 8,000 acre-ft per year as potable water. At present costs of $75/acre-ft for imported Colorado River water, it would cost $600,000 per year if all its fresh water had to be imported.

Future for Recharge Program

The successful recharge/water resource management program at Camp Pendleton will continue to save both water and money into the foreseeable future.

Anticipated improvements include updating of all treatment plants to secondary treatment; mechanical aeration of all oxidation ponds; and nutrient removal either by tertiary in-plant treatment or by proper flooding/drying techniques as practiced at Flushing Meadows, Arizona.

EASTERN MUNICIPAL WATER DISTRICT (HEMET, CALIFORNIA)

Introduction

The Hemet-San Jacinto groundwater basin is an important source of irrigation and potable water for the local area. The basin is essentially a closed system with a long-term yield of 11,000 acre-ft per year. However, an overdraft condition exists as over 23,000 acre-ft are being withdrawn each year.

Authorities estimate that by 1980, 10,800 acre ft/yr of wastewater will be available to the region for irrigation and limited recharge(1), which would amount to a doubling of the long-term basin yield. Conservation and replenishment of the groundwater resource reduces the need for imported Colorado River water of high mineral content for irrigation and domestic use, and therefore retards degradation of the high quality groundwater by this source.

In July, 1965, the Eastern Municipal Water District completed the construction of and began operating a new 2.5 MGD activated sludge treatment plant in conjunction with a new trunk sewer system. Soon after, the EPA provided funds for a project to demonstrate the feasibility and safety of recharging groundwater basins with the treated secondary effluent. Since that time, treated wastewater from the Hemet-San Jacinto treatment plant has been spread in percolation basins both as a method of disposal and for replenishment of the groundwater basin. In 1971, the Hemet-San Jacinto plant was expanded to 5 MGD capacity, but currently (1975) flow is only about 3 MGD with equal volumes going to local irrigation and groundwater recharge.

Municipal Treatment

The treatment plant at Hemet-San Jacinto is a conventional activated sludge plant. A chlorine contact chamber follows the final clarifiers to provide a 20 minute contact time prior to two 1.5 MG flow equilization ponds. In addition, three emergency storage ponds are available and a sealed brine evaporation pond maintained to receive tank truck deliveries of brine water generated by a local water softening industry.

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(1) The recently adopted basin plan for the Santa Ana River Basin (RWQCB, Santa Ana Region) essentially precludes continuation of the present effluent recharge program at Hemet. In the future, effluent not used for irrigation will be substantially diluted with imported fresh water prior to recharge.

The final effluent is then transported by four pumps (two 50 H.P. electric and two 250 H.P. gas motors) one mile out to the spreading basins via two pressure mains (20 in and 14 in). Water sold for irrigation is taken directly from these force mains.

Table A-3 summarizes typical effluent quality characteristics for the treatment plant.

Recharge Program

The recharge area is located approximately four miles east of the plant site and is comprised of 10 ponds covering an area of approximately 16 acres. The ponds are arranged in two parallel groups with the effluent main running along the median strip. The reclaimed water can be diverted to any combination of ponds via individual tees, valves, and meters with a nominal size of 8 in. The effluent drops into each pond from an upturned elbow onto a concrete splash pad. The basins are interconnected with overflow gates to allow transfer of water from one basin to another.

The basins are filled on a rotational basis with maximum infiltration rates achieved by following the schedule: fill - 1 day (to average 2.5 ft depth), drain - 2 days, dry - 1 day. When longer cycles of two or three weeks were tried, clogging of soil pores and reductions in infiltration rates resulted. Much of this clogging was caused by algae growths stimulated by the high nutrient concentrations in the reclaimed water. (See Table A-3.) Apparently, the shorter flooding-drying cycle effectively interrupted the algae life cycle and eased this problem.

The soil profile in the spreading area shows medium and coarse sand down to approximately 50 ft with horizontal clay layers interspersed at greater depths. Infiltration rates are fairly high at roughly two to three ft per day when short flooding-drying cycles are used. Experimentation showed that infiltration rates were not enhanced by vegetative or gravel cover in the basins. To control vegetation and also to prevent surface clogging, the basins are periodically rototilled.

Table A-3. AVERAGE MUNICIPAL EFFLUENT CHARACTERISTICS AT HEMET, CALIFORNIA

Constituent	Concentration (mg/l)
BOD	15-25
SS	15-20
TDS	700
Na	145
Cl	114
pH	7.6
Hardness (as $CaCO_3$)	208
Ca	75
Mg	12
K	19
NH_4	15
NO_3	24
CO_3	0
HCO_3	359
SO_4	131
Fl	0.8
B	0.7

Monitoring facilities consist of ten (160-200 ft) wells, a network of peizometer holes at various depths from 10 to 24 ft, and a shallow test pan unit for sampling under one of the basins at two, four, six, eight, ten ft depths. Table A-4 shows the effects of percolation on the effluent characteristics.

As shown in the table, nitrate concentration increased rapidly in the first two feet due to oxidation of ammonia. Total COD decreased 68 percent through eight ft of soil while total hardness increased from 205 to 340 mg/l through the same depth. The coliform concentration dropped sharply to a level of 120 per 100 ml while fecal coliform concentration dropped from 58,000 to only 10 MPN per 100 ml.

Efforts to trace the percolating groundwater down to the present water table at 200 ft have failed due to horizontal displacements caused by layers of silt and clay. It is generally agreed, however, that the only degradation of the groundwater basin caused by recharge with secondary effluent has been a gradual increase of groundwater TDS over the long term.

Economics

Annual costs for the recharge operation only (including effluent pumps, four miles of main pipeline, equipment, meters, ponds, labor, overhead) are as follows:

	$/year (1972)
. Equipment amortization, overhead	6,500
. Maintenance of basins	15,000
. Repairs	600
Total	$ 22,100

Therefore, total costs for recharge are $22,100 per year (1972), for an average flow for two MGD (assuming one mgd to irrigation), or approximately $30 per MG. This represents approximately 15 percent of the total cost of wastewater treatment and disposal. As shown, the main operational cost appears as maintenance of the basin berms and percolation surfaces (rototilling).

Future for Recharge Program

Groundwater recharge will probably play an important part in the water resource management program of the Hemet-

Table A-4. EFFECTS OF PERCOLATION ON EFFLUENT CHARACTERISTICS

Constituent	Depth (ft)				
	0	2	4	6	8
NO_3^-N (mg/l)	13	29	28	25	30
COD (mg/l)	50	20	17	17	16
Total hardness (as mg/l $CaCO_3$)	205	180	330	350	340
Coliform, MPN per 100 ml	250,000	1,000	1,000	180	120

San Jacinto basin area. To a great extent, however, use of secondary effluent is being shifted from direct recharge to agricultural irrigation. Increases in groundwater TDS and state health department fears that organo-phosphate pesticides and viruses (potentially present in the effluent) may degrade groundwater supplies have reduced the appeal of effluent as a recharge source.

In the event that primary use of wastewater shifts again to direct recharge, low TDS state project water can be blended with wastewater to achieve an acceptable TDS level in the recharge water.

NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS/THE U.S. GEOLOGICAL SURVEY (LONG ISLAND, NEW YORK)

Introduction

The U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, conducted a series of artificial recharge experiments at Bay Park, New York, from 1968 to 1973. The purpose of these experiments was to obtain some of the scientific and economic data needed to evaluate the feasibility of injecting reclaimed wastewater (tertiary treated sewage) into a proposed network of barrier-recharge wells in an area of potential seawater intrusion.

Groundwater is the only local source of water on Long Island. The demand for this water has been increasing steadily with the population, while a massive expansion of sewage collection systems has reduced recharge from cesspools and septic tanks by collecting and discharging effluents to the ocean.

The main concern presently is that the productive Magothy aquifer will become depleted over the years, forcing the purchase of imported water. The lowering of the water table and the potentiometric head in the Magothy will also increase the risk of salt water intrusion.

Municipal Treatment

The Nassau County Public Works Department constructed an 0.6 mgd pilot tertiary treatment plant in 1968 to upgrade activated sludge secondary effluent to drinking water quality for the recharge tests. Figure A-2 on the following page shows a flow diagram of the advanced treatment system.

The tertiary facility consisted of: chemical coagulation/clarification, filtration, carbon adsorption, and chlorination. The upflow clarifier was 40 feet in diameter, had a rise rate of 720 gpd/sq ft, and used a 225 mg/l alum dosage as its principal coagulant. Two ten ft diameter dual media filters followed, comprised of three feet of anthracite over one foot of sand, and were operated at a hydraulic loading of 3.3 gpm/sq ft. The effluent was then pumped to four activated carbon towers operated in series. Each tower was 8 ft in diameter, and was packed with 7,000 lbs of activated carbon. Total empty bed contact time was 30 minutes. The activated carbon was regenerated in a multi-hearth, gas-fired furnace. Conventional chlorination completed the treatment chain.

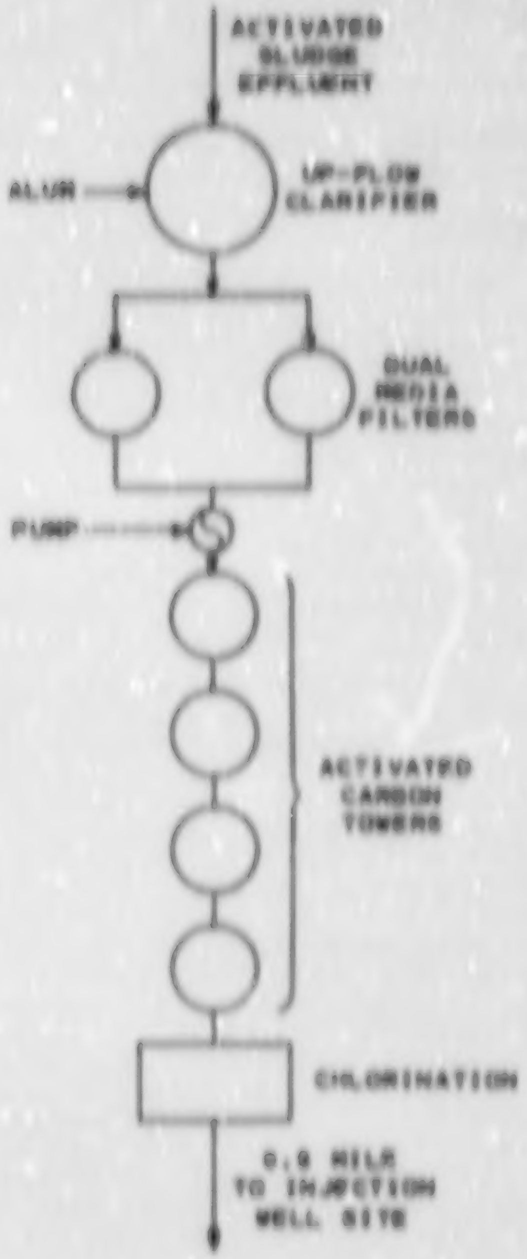
ACTIVATED
SLUDGE
EFFLUENT
ALUM
UP-FLOW
CLARIFIER
DUAL
MEDIA
FILTERS
PUMP
ACTIVATED
CARBON
TOWERS
CHLORINATION
0.5 MILE
TO INJECTION
WELL SITE

FIGURE A-2
TERTIARY TREATMENT PLANT AT
LONG ISLAND, N.Y.

The effluent was then pumped 1/2 mi in a six in. line to a small holding tank at the injection well site. This tank provided two hrs. of storage to provide for continuous injection during brief treatment plant shutdowns.

Table A-6 summarizes typical effluent quality of the tertiary effluent for recharge.

Recharge Operation

Facilities - At the injection well site, additional treatment including degasification, pH adjustment, and dechlorination, were available if desired. Later tests were to show that none of these provided any significant improvement in operations. Figure A-3 depicts the injection facilities.

Reclaimed wastewater and/or fresh water to be injected was stored in a 50,000 gal tank (providing roughly two hours of retention). If pH control chemicals were to be used, they were introduced at the tank outlet where the water discharged into a splashbox for mixing. Optional cascade degasification followed in a few tests after which the water was pumped down the well.

The injection well complex consists of two wells within a single drill hole, 36 in. in diameter. The major element is an 18 in. diameter fiberglass casing that extends to a depth of 610 ft below land surface. A stainless steel screen 16 in. in diameter and 62 ft in length was attached to the bottom of the 18 in. casing in the Magothy aquifer. Various smaller pipes for monitoring were also housed in the casing. See Figure A-4 for a detail of the well.

The injection pump assembly consists of a 60 HP electric motor connected to a centrifugal pump through a variable speed hydraulic transmission. This system allows the injection rate to be controlled in the range from zero to more than 600 gpm against a maximum head of 100 psi.

The well facility also includes a redevelopment or backwash pump. The major element of this system is a 50 HP vertical deep-well turbine pump, which is suspended in the injection well at a depth of 150 ft. The backwash flow can be controlled within the range of 200-1,000 gpm.

In addition to sampling of water during well "redevelopment," fourteen wells, ranging in depth from ten to 726 ft, were used to monitor water quality at various depths and distances from the point of injection.

Table A-5. TYPICAL TERTIARY EFFLUENT CHARACTERISTICS AT LONG ISLAND, NEW YORK (1)

Parameter	Concentration (mg/l)
COD	9
BOD	5
SS	0-1
TDS	394
Cl^-	99
SiO_2	13
Total Al	0.1
Total Fe	0.4
Total Mn	0.07
Ca	20
Mg	6.4
Na	86
K	13
HCO_3	59
SO_4	160
Chlorine residual	2.1
F	0.3
Org. N	0.6
NO_2	0.01
$NH_4 - N$	23
NO_3	0.1
Total P as PO_4	0.08
Hardness as $CaCO_3$	79
pH	6.1
Color (platinum cobalt scale)	2
Turbidity as SiO_2	0.4
DO	4.5
Coliforms/100 ml	≤ 1
Fecal Coliforms/100 ml	≤ 1
Fecal Streptococci/100 m.	≤ 1

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(1) Vechioli, John, Oliva, J. A., Ragone, S. E., and Ku, H. F. H., 1975, Wastewater Reclamation and Recharge, Bay Park, N.Y., ASCE, Env. Eng. Div., V. 101, No. EE2.

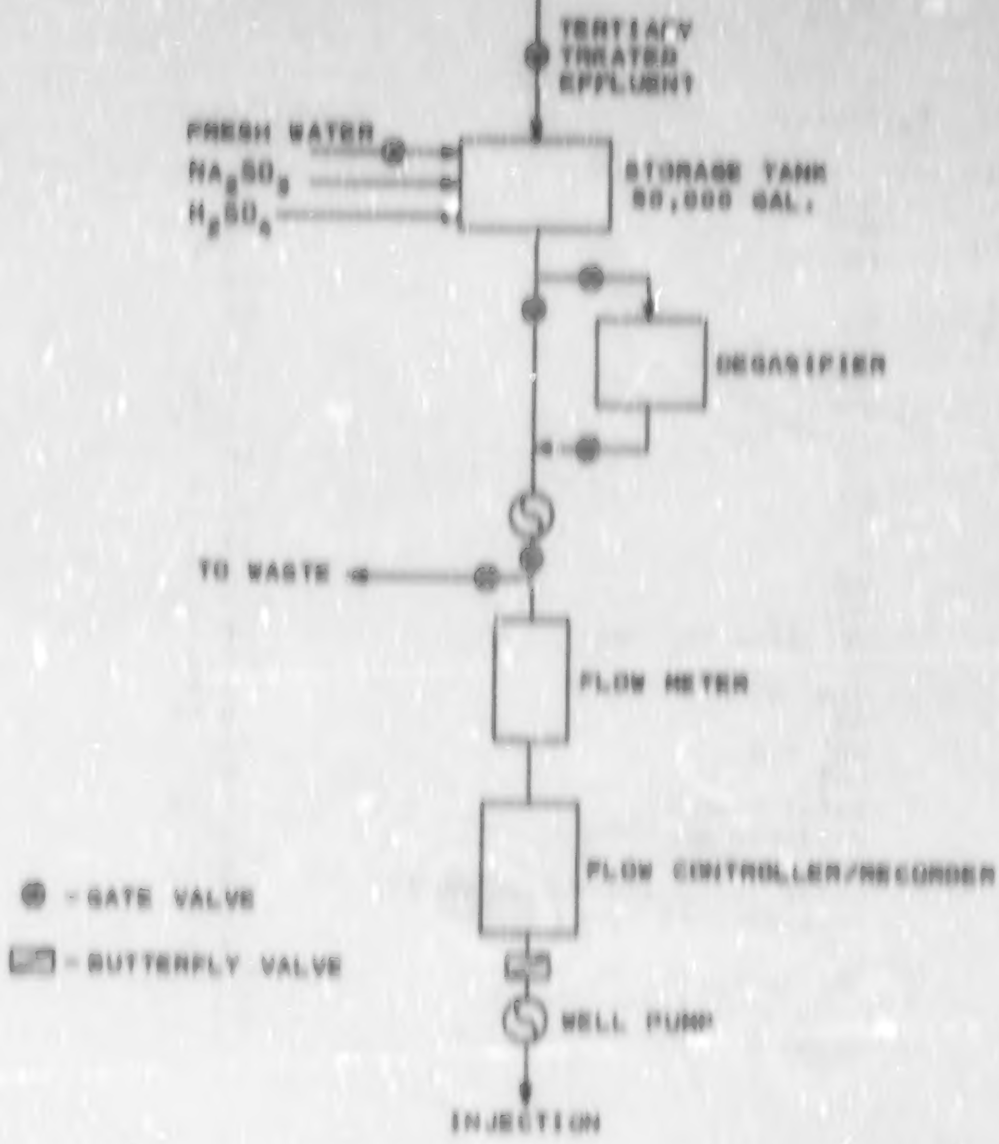

TERTIARY
TREATED
EFFLUENT
FRESH WATER
NA_2SO_3
H_2SO_4
STORAGE TANK
50,000 GAL.
DEGASIFIER
TO WASTE
FLOW METER
FLOW CONTROLLER/RECORDER
WELL PUMP
INJECTION
● - GATE VALVE
- BUTTERFLY VALVE

FIGURE A-3
INJECTION FACILITIES AT BAY PARK,
LONG ISLAND, N.Y.

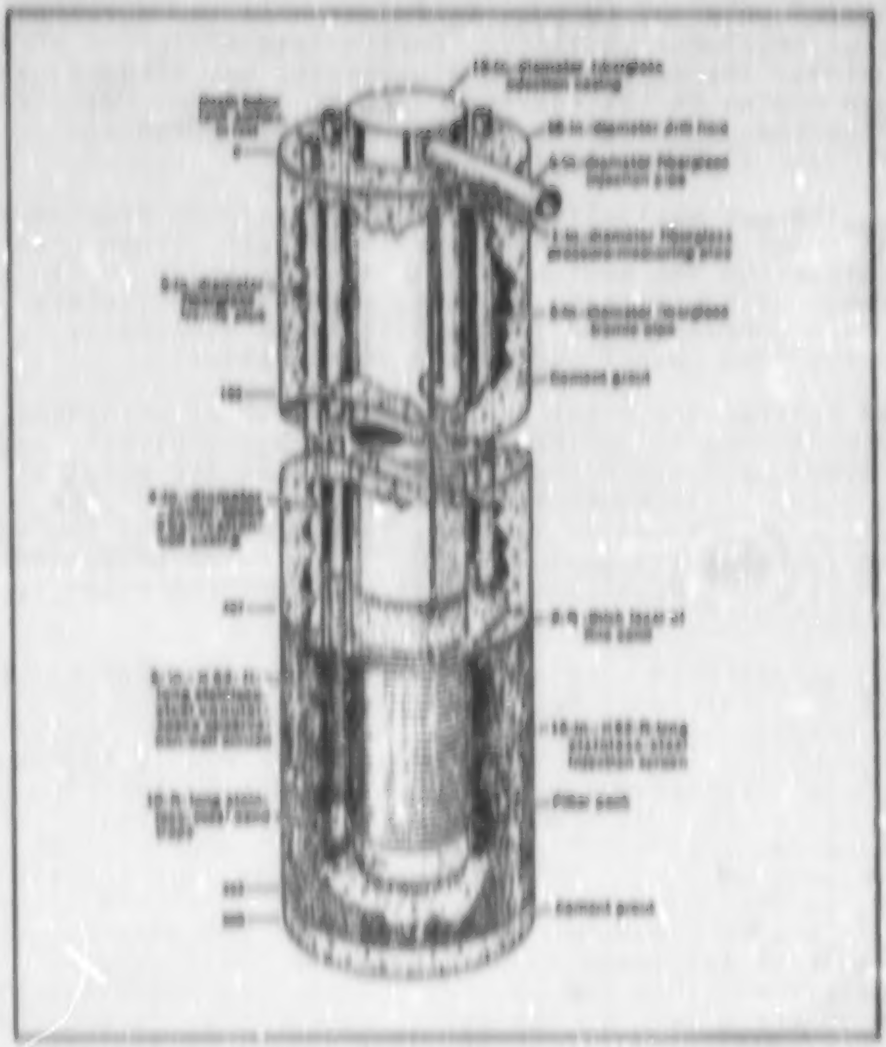

16-in. diameter fiberglass injection casing
48-in. diameter drill hole
8-in. diameter fiberglass injection pipe
1-in. diameter fiberglass pressure-measuring pipe
3-in. diameter fiberglass ... pipe
Cement grout
0
100
2-ft thick layer of fine sand
16-in., 100-ft long stainless steel injection screen
Filter pack
Cement grout

FIGURE A-4

DETAILS OF THE BAY PARK INJECTION WELL

TAKEN FROM COHEN, P. AND C.N. DURFOR. "DESIGN & CONSTRUCTION OF A UNIQUE INJECTION WELL ON LONG ISLAND, N.Y." U.S. GEOLOGICAL SURVEY, PROF. PAPER 550-D, PAGES D 253-0257.

Results - The series of continuous pumping tests (a 33-day continuous test and a 6-month interrupted test) during the 1968-1973 period showed that successful injection of high quality tertiary effluent into the deep Magothy aquifer was achieved only during peak performance of the advanced wastewater treatment facility. During less efficient treatment periods, the main problem encountered was clogging of the fine pore spaces in the aquifer, forcing frequent well regeneration (backwashing) to restore initial hydraulic specific capacity (recharge rate/head.

The clogging was basically a physical, straining problem. Although loading rates of 0.6 gpm/ft^2 of well screen area were achieved in the medium sand aquifer (similar to the lower range of a slow sand filter), residual particulate matter, and phosphate and iron precipitates frequently clogged the pore spaces and forced regeneration.

The head buildup distribution in the aquifer at distances of 20 to 200 ft from the point of injection was virtually equal to the drawdown distribution observed during the original pumping test. This would indicate that clogging of the aquifer was restricted to the immediate vicinity of the well. This was corroborated during regeneration after injection when the first slugs of water recovered were consistently high in turbidity and iron.

Clogging accelerated with several minor quality changes; i.e. when effluent turbidity increased over 0.5 mg/l or PO_4^{-3} concentrations climbed above 1.0 mg/l, or Fe rose above 0.5 mg/l. The iron problem had been almost eliminated by the end of the project by frequent backwashing of the carbon towers. This maintained aerobic conditions throughout the towers. Thus iron compounds precipitated there instead of in the well as had occurred when anaerobic bacteria in the carbon had reduced iron to a soluble state before injection. Another improvement was the elimination of the peak solids loads occurring in the first slug of effluent after filter backwashing. This slug was discharged instead of being sent to the well. Authorities agreed that future reclamation/injection projects should be designed with large effluent storage capacity to provide greater flexibility in by-passing surge loads from the treatment plant and in assuring continuous injection during periods of treatment plant shutdown.

Other sources have stated that well clogging problems can be caused by the release of entrained air or dissolved gases from the injected water. The dissolved gases can themselves clog soil pores, or excessive amounts of free oxygen, by establishing aerobic conditions, can cause the oxidation of iron, aluminum, and phosphorous to insoluble precipitate forms which clog the aquifer. However, five tests at Long Island showed that clogging caused by gas entrainment was minimal compared to the clogging effects of other parameters (turbidity, iron, phosphate). Thus, degasification was rarely used.

Significant changes did not occur in the chemical characteristics of the injected water as it moved through the aquifer for distances up to 20 ft. The slight changes which did take place included a decrease in calcium, bicarbonate, pH, and phosphate. Iron, on the other hand, increased.

Economics

Operation and maintenance costs for the 1968-1973 advanced water reclamation/groundwater recharge program were as follows:

	$/MG (1972 $)
. Treatment plant	
Labor	120
Chemicals	20
Utilities	10
Other	120
. Injection facility	
(power, chemicals, labor)	50
TOTAL (1972 $)	320

Capital costs for the injection well were approximately $125,000 and $860,000 for the tertiary treatment plant (1972 $).

Future for Recharge Programs

Although this test showed that injection into the deep Magothy aquifer to establish a salt water intrusion barrier and to replenish the groundwater supply was difficult, authorities of the USGS and Nassau County Department of Public Works feel that recharge does have potential at Long Island.

A new system is currently in the design phase that would provide 5 mgd of tertiary treated effluent for recharge of the upper glacial and Magothy aquifers. They hope to replenish the shallow aquifer at a location in the middle of the island where a vertical gradient exists, allowing recharged water to percolate to the deeper Magothy aquifer.

The 5 mgd plant will consist of: grit removal; biological treatment for carbonaceous removal; lime clarification for phosphate and solids removal; biological nitrification/denitrification to reduce nitrogen concentrations; dual media filtration for further suspended solids removal; activated carbon adsorption to remove dissolved organics; and finally chlorination for bacteriological control.

A group of 100 foot wells along with several percolation basins will be used to recharge the shallow groundwater basin. This aquifer is composed of coarse sand with large pore spaces, and therefore clogging problems are not expected to be as severe as in the deep well tests. Spreading basins will be used where feasible (some old basins from the 1930's are still being used for storm water runoff collection and percolation), with the effluent and available storm water being mixed and recharged.

The effluent to be recharged will undergo advanced wastewater treatment as listed above to bring it up to drinking water standards prior to injection or percolation. No mixing with fresh water sources will be necessary for many years because the TDS of the effluent will be approximately 400 µg/l. Eventually, some type of demineralization will be necessary to maintain a proper salt balance in the aquifers.

Ultimately, authorities hope to recharge approximately 100 mgd of combined treated wastewater and natural runoff throughout Nassau County by percolation and injection. This large scale recharge would repreuent roughly 10 percent of the total recharge to the Long Island groundwater basin. In this way Nassau County hopes to conserve their high quality groundwater supply and to avoid purchase of costly imported water from New York City.

THE CITY OF OCEANSIDE, CALIFORNIA

Introduction

The city of Oceanside, California, has been extracting groundwater for its potable supply since the 1930's. By 1956, however, increasing demands had drastically lowered the water level in the aquifer, and salt water intrusion had become significant.

Therefore, in 1956 the city initiated a groundwater recharge program using primary effluent. The wastewater was pumped three miles inland and percolated to replenish the basin and to retard salt water instrusion.

As the population continued to increase and two more treatment plants were constructed, the total recharge program overloaded the localized groundwater basin capacity, and the water table rose to fifteen ft above sea level. By 1970, the basin in the area of recharge had become saturated, and effluent was flowing as a stream into the ocean.

An outfall was constructed to temporarily discharge the effluent to the ocean while a new secondary treatment plant and percolation basins were constructed. The new basins, approximately six miles inland, are located further upstream than the old spreading areas at a site where the aquifer can accept a greater volume. Ultimately, all the effluent will be extracted downstream from the percolation areas and used for irrigation and filling of recreational lakes. Any excess effluent will be discharged through the ocean outfall.

Municipal Treatment

When the San Luis Rey treatment plant is completed in early 1975, the single primary plant will be closed, leaving one other secondary plant and the new facility to treat the city's wastewater.

Both plants are conventional activated sludge plants although the new San Luis Rey plant has optional chemical precipitation for nutrient removal. Before the effluents are pumped to the spreading grounds, however, they enter a series of five, five to ten acre oxidation ponds (no aeration) and/or a 100 acre-ft effluent-filled pond called Whelan Lake. The pond is clay-lined and has a floating 50 HP brush aerator to maintain aerobic conditions. Two additional lakes may provide further storage at the spreading site. Thus the total effluent flow from the two plants of 6.5 mgd is stored from ten to 20 days in ponds before being recharged.

Table A-6 summarizes typical effluent characteristics of the discharge from Whelan Lake. The high TDS concentration is due to three factors: the use of high TDS Colorado River water as part of the potable supply; the infiltration of salt water into the sewer lines near the coast; and evaporation in the oxidation ponds and Whelan Lake.

Recharge Program

Figure A-5 provides a schematic diagram of the present and planned facilities. The new recharge program to begin in 1975 will consist of pumping 6.5 mgd of treated wastewater from Whelan Lake in a two mile 33 in. diameter pipeline to two series-operated oxidation ponds. The effluent will then flow to the percolation area which will cover a total of 80 acres dyked into several basins. The basins are of coarse sand composition with high infiltration rates of four to five ft/day. They will be flooded to a three ft. depth in a flooding-drying cycle such that several basins are being flooded while the others are drying. The basins will be periodically scarified to reduce bottom clogging by solids.

The current plan is to construct extraction wells 1/2 miles downstream from the recharge basins. With the finished system, all treated wastewater percolated will be extracted by the wells and used for irrigation and for filling recreational lakes. With this percolation/extraction system, all groundwater gradients in the recharge area will be directed toward the extraction wells thus ensuring that no renovated water volumes of any significance will migrate directly into the native groundwater. After extraction, a portion of the water will be demineralized to a TDS of 850 mg/l before irrigation reuse. In this way, the salt content of the groundwater basin will not be significantly increased due to percolation of the irrigation water.

Monitoring of the groundwater to check for possible degradation will be carried out downstream from the percolation basin. Existing wells of roughly 100 ft depth will be used to collect the samples for this purpose.

Economics

Table A-7 on page 64 summarizes basic estimated capital and operation and maintenance costs for the complete recharge portion of the Oceanside system. Annual capital recovery costs are $263,000 (1972 $) per year at a 5.5 percent interest for a 25 year life. Adding the annual operation and maintenance cost of $85,000 yields a total annual cost of $348,000 (1972 $) or, $147 per mg, at 6.5 MGD.

Table A-6. TYPICAL CHARACTERISTICS OF TREATED WASTEWATER FOR RECHARGE AT OCEANSIDE, CALIFORNIA

Constituent	Concentration (mg/l)	Constituent	Concentration (mg/l)
BOD	6	F^-	0.86
SS	18	B	0.72
TDS	1280	Fe	0.07
Na^+	285	Total Cr	$\leqslant$ 0.05
Cl^-	303	Zn	$\leqslant$ 0.05
Coliform	3-43/100 ml	As	$\leqslant$ 0.01
$SO_4^=$	453	Pb	0.05
Total Org. N	1.3	Cu	$\leqslant$ 0.01
$NO_3^=$	2.2	Se	$\leqslant$ 0.01
NH_3	20	Cu	$\leqslant$ 0.01
PO_4^{-3}	31	Cd	$\leqslant$ 0.05
		Ag	$\leqslant$ 0.05

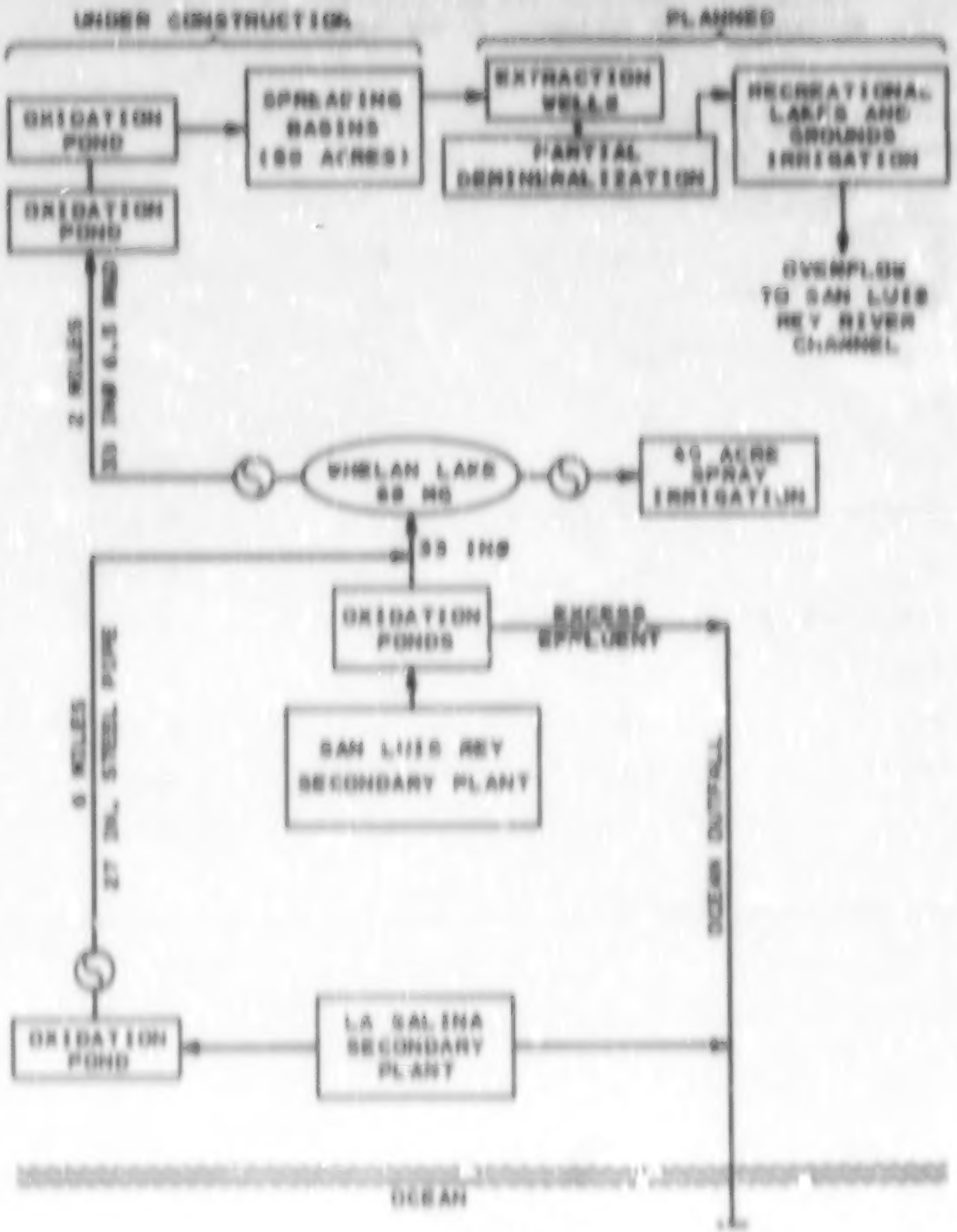

UNDER CONSTRUCTION
PLANNED
OXIDATION POND
SPREADING BASINS (80 ACRES)
EXTRACTION WELLS
PARTIAL DEMINERALIZATION
RECREATIONAL LAKES AND GROUNDS IRRIGATION
OXIDATION POND
OVERFLOW TO SAN LUIS REY RIVER CHANNEL
2 MILES
20 INCH 6.5 MGD
WHELAN LAKE 68 MG
40 ACRE SPRAY IRRIGATION
33 INS
OXIDATION PONDS
EXCESS EFFLUENT
6 MILES
27 IN. STEEL PIPE
SAN LUIS REY SECONDARY PLANT
OCEAN OUTFALL
OXIDATION POND
LA SALINA SECONDARY PLANT
OCEAN

FIGURE A-6
PRESENT AND PLANNED RECHARGE FACILITIES
AT OCEANSIDE, CA.

Table A-7. ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS FOR RECHARGE SYSTEM AT OCEANSIDE, CALIFORNIA

Capital Cost	$1000 (1972)
. Effluent force mains	
33 in Ø, 1/2 mile	300
33 in Ø, 2 miles plus pump station	560
. Improvements to Whelan Lake & existing spreading grounds	180
. Construction and installation of standby aeration and chlorination facilities and flow meter	230
. Construction of new spreading basins and flow meter	120
. Construction of extraction wells and facilities to transport percolated wastewater to recreational lakes	240
. Demineralization plant (for a portion of the flow)	1500
. Land acquisition (45 acres)	200
. Engineering contingencies	200
Total Capital Cost for Recharge/Reclamation System Only	$3,530

Operation & Maintenance Cost (Annual)	$1000 (1972)
. Estimated Labor	15
. Estimated Power Costs	70
Total O & M Cost for Recharge/Reclamation System	$ 85

Authorities feel that the extensive benefits that would be realized with this system offset the cost of the reclamation facilities. Not only will high quality renovated water be available for irrigation of park land and filling of recreational lakes, but groundwater supplies will be conserved, and valuable ocean and coastline assets will be protected by elimination of most effluent discharges to the ocean.

Future for Recharge Programs

Future plans for groundwater recharge/reclamation systems in Oceanside are contingent upon the success of the program presently being constructed.

By the year 2000, expected sewage flow from the city will be 15 mgd. It is anticipated that all this wastewater will be fed to the recharge/renovation system for reuse in recreational lakes and for irrigation.

ORANGE COUNTY WATER DISTRICT (FOUNTAIN VALLEY, CALIFORNIA)

Introduction

Since the 1950's, continued overdrafting of the Orange County groundwater basin has lowered the groundwater table to below sea level, resulting in significant salt water intrusion. The intrusion occurs at the mouth of an ancient underground channel cut millions of years ago by the Santa Ana River. The years of continuous flows of the river, which formed the alluvial fan now known as Orange County, have buried this ancient river under several feet of clay.

In order to prevent further seawater intrusion, which was evident as far as six miles inland, and to replenish existing groundwater sources, the Orange County Water District is constructing a 30 mgd wastewater reclamation and desalting plant. Effluent from this plant will be injected in to 23 multi-point wells to form a salt water intrusion barrier and to recharge the groundwater basin. Seven extraction wells, located two miles seaward from the injection line, will extract intruding salt water before it reaches the barrier and return it to the ocean. The combination of salt water extraction and fresh water injection will serve to create an underground hydraulic pressure mound preventing intrusion.

The total 30 mgd supplied by the advanced wastewater treatment plant and the seawater desalting plant will supply a volume equivalent to roughly ten percent of the total Orange County water demand.

Municipal Treatment

Ultimately the wastewater treatment facility and the desalting plant will each supply fifteen mgd which will be blended to provide 30 mgd of 500 mg/l TDS water for recharge. At startup, the desalter will be operated to produce three mgd with plans to expand following a trial period. Initially, the wastewater reclamation plant will provide roughly eleven mgd. An additional nine mgd, temporarily supplied by deep wells, will be mixed with the reclaimed and desalted waters to lower TDS within required limits. The deep well water is also needed temporarily to satisfy the state requirement that reclaimed water injected directly to the groundwater must be blended 50:50 with a fresh water supply regardless of the treated effluent quality. The use of deep well water will be terminated when full scale operation is achieved. The remainder of this section will deal only with the advanced wastewater treatment plant.

FIGURE 3-4

CROSS-SECTION OF HYDRAULIC
SEAWATER BARRIER AND RECHARGE
SYSTEM, ORANGE COUNTY, CA.

The Orange County Water District advanced wastewater reclamation plant is one of the most sophisticated in the world. Ultimately it will provide tertiary treatment to fifteen mgd of secondary effluent from the adjacent Orange County Sanitation District's trickling filter plant.

Figure A-7 shows a flow diagram of the basic treatment units. Detailed design criteria are provided in Table A-8.

The secondary effluent first enters the two chemical flocculation/clarification basins. Each unit consists of a small rapid mix tank, flocculation chamber, and settling basin. The main purpose of these units is to remove suspended solids and phosphates, and also to raise the pH to facilitate subsequent ammonia stripping. In addition, calcium, magnesium, many trace elements, bacteria, and virus may also be removed by the chemical clarification.

Conventional ammonia stripping in plastic media, forced draft towers follows;after which the water is recarbonated.

A first stage recarbonation chamber lowers the pH from 11.0 to 9.3 by diffusing carbon dioxide gas, supplied by compressed stack gases from the lime recalcining furnace, into the wastewater. The recarbonated water is then held for 40 minutes in an intermediate settling basin to allow complete formation and some sedimentation of calcium carbonate. The sludge from the basin is continually removed and returned to the initial clarification tank to aid in flocculation and settling. The third section of the basin is the secondary recarbonation chamber where the pH is lowered from 9.3 to 7.5 to drive all excess calcium carbonate back into solution to prevent deposition and scale formulation on following filter beds and piping.

The process stream is then given multi-media (anthracite coal, silica sand, and garnet sand) filtration to remove suspended solids and colloidal material. The filters are periodically backwashed with final blended product water.

Following filtration, the water is pumped up through carbon towers that provide a 30 minute contact time for the adsorption of organics onto the carbon particles. The carbon towers are effective in removing color and odor as well. A carbon regeneration furnace will be used to regenerate spent carbon from the towers.

Effluent from the carbon adsorption process flows to the chlorine contact basin for breakpoint chlorination to oxidize any residual ammonia, and to destroy an remaining bacteria and virus. Chlorine will be added, through a diffuser in the pipeline, just upstream of the entrance to the contract basin.

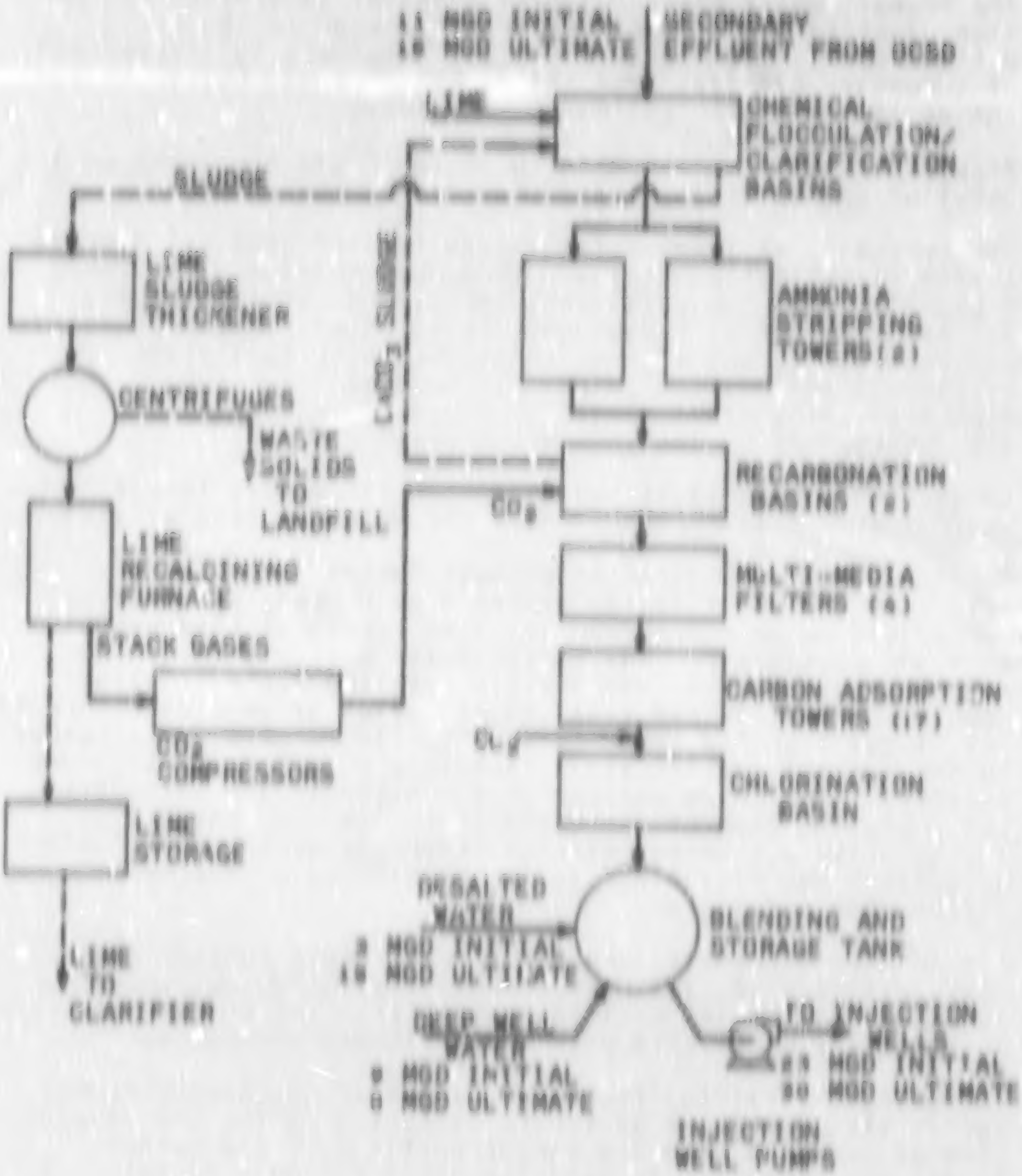

11 MGD INITIAL
15 MGD ULTIMATE
SECONDARY EFFLUENT FROM OCSD
LIME
CHEMICAL FLOCCULATION/ CLARIFICATION BASINS
SLUDGE
$CaCO_3$ SLUDGE
LIME SLUDGE THICKENER
AMMONIA STRIPPING TOWERS(2)
CENTRIFUGES
WASTE SOLIDS TO LANDFILL
RECARBONATION BASINS (2)
CO_2
LIME RECALCINING FURNACE
MULTI-MEDIA FILTERS (4)
STACK GASES
CARBON ADSORPTION TOWERS (17)
CO_2 COMPRESSORS
CL_2
CHLORINATION BASIN
LIME STORAGE
DESALTED WATER
3 MGD INITIAL
15 MGD ULTIMATE
BLENDING AND STORAGE TANK
LIME TO CLARIFIER
DEEP WELL WATER
9 MGD INITIAL
0 MGD ULTIMATE
TO INJECTION WELLS
23 MGD INITIAL
30 MGD ULTIMATE
INJECTION WELL PUMPS

FIGURE A-7
ORANGE COUNTY WATER DISTRICT
ADVANCED WASTEWATER RECLAMATION PLANT,
FOUNTAIN VALLEY, CALIFORNIA

Table A-8. DESIGN PARAMETERS FOR ORANGE COUNTY WATER DISTRICT WATER RECLAMATION PLANT (MGD)

- Clarification Basins

Rapid Mixing:

Number of basins: 2
Each basin equipped with a mechanical mixer
Detention time: 1 minute (each basin)

Flocculation:

Number of 3-compartment basins: 2
Each compartment equipped with mechanical flocculator
Detention time: 30 minutes

Settling:

Number of basins: 2
Overflow rate: 1560 gpd/ft^2
Detention time: 85 minutes
Each basin equipped with settling tubes

- Ammonia Stripping Towers

Number of towers: 2
Hydraulic loading: 1 gpm/ft^2
Air flow: 400 ft^3/gallon
Depth of packing: 25 ft. (7.6 m)
Number of 10 ft. diameter fans: 12
(develop 350,000 cfm air flow) each
Heat transfer capacity: Cool seawater desalting plant waters to 80° - 85°F and heat ammonia stripping air to 87° - 97°F.

- Recarbonation Basins

Number of 3 compartment basins: 2
1st and 2nd stage recarbonation detention times: 15 min. each
Settling basin detention times: 40 min.
1st stage recarbonation basin equipped with mechanical flocculators

---

Table A-8 (continued). DESIGN PARAMETERS FOR ORANGE COUNTY WATER DISTRICT WATER RECLAMATION PLANT (MGD)

- Sludge Handling

Sludge Pump Station:

Number of pumps: 3
Pump capacity: 700 gpm at a total head of 35 feet (10.7m)

Sludge Thickener:

Flow: 1000 gpm
Surface overflow rate: 1000 gpd/ft^2
Surface dry solids loading: 200 lbs/day/ft^2 (90.7 Kg/day/m^2)
Thickened sludge solids: 8%-20%

- Lime Recalcining

Lime Recalcining Furnace:

Capacity dry CaO: 30 tons/day

Lime Storage Tanks:

No. of tanks: 2
Capacity: 35 tons bulk quicklime (CaO) ea.

Centrifuges:

No. of centrifuges: 2
Capacity: 2000 lbs/hr each

Lime Feeders and Slakers:

No. of feeders and slakers: 2
Capacity: 4000 lbs/hr each

CO_2 Compressors:

No. of compressors: 3
Capacity: 1600 cfm each

Table A-8 (continued). DESIGN PARAMETERS FOR ORANGE COUNTY WATER DISTRICT WATER RECLAMATION PLANT (MGD)

- Multi-Media Filtration

Design Criteria

Plant Capacity:

15 mgd
16,800 a.f./year
20,714,400 m^3/yr.
10,400 gpm
23 cfs

Filtration:

No. of filters: 4
Hydraulic loading: 5 gpm/ft^2

Backwash rate: 15 gpm/ft^2

Surface Wash flow: 0.8 gpm/ft^2

Backwash water receiving tank
capacity: 160,000 gal

- Carbon Adsorption

Carbon Adsorption:

No. of upflow pressure units: 17
Contact Time: 30 min
Carbon volume, ea. unit,
2700 ft^3
Tank diameter: 12 ft
Carbon depth: 24 ft
Hydraulic loading: 5.8 gpm/ft^2

Carbon Regeneration Furnace:

Capacity, dry carbon:
12,000 lbs/day

Table A-8 (continued). DESIGN PARAMETERS FOR ORANGE COUNTY WATER DISTRICT WATER RECLAMATION PLANT (MGD)

- Chlorination Basin/Blend Tank/Backwash Water Tank

  Chlorination Basin:

  1 basin - inline feeding and mixing
  Contact time: 30 minutes

  Blending Reservoir:

  1 basin - prestressed concrete
  Capacity: 1 million gallons
  100 feet (30.4m) diameter x 20 feet deep

  Backwash Water Receiving Tank:

  1 underground concrete basin
  Capacity: 160,000 gallons
  Pumping capacity: 800 gpm (50.46 L/sec)

- Injection Pump & Chlorine Supply Station

  Chlorine Feeders:

  Number of feeders: 3
  Feeder capacity: 1000 lb/day each
  On-site chlorine manufacturing: 3000 lb/day

  Injection Pumps:

  Number of pumps: 4
  Type: vertical turbine
  Engine type: natural gas
  Pump capacity: 5000 to 7200 gpm

  Backwash Pump:

  Number of pumps: 1
  Type: vertical turbine
  Engine type: electric
  Pump capacity: 15 gpm

Effluent from the chlorination basin flows by gravity to the blending and storage reservoir where it will be blended with desalted water and/or deep well water to achieve a final TDS of 550 mg/l; as required by the local Water Quality Control Board.

Table A-V summarizes secondary effluent characteristics from the OCSD trickling filter plant, expected final reclaimed water characteristics, and expected final blended recharge water characteristics.

Solids handling is extensive, including sludge thickening, centrifugation, and recalcination in a lime reclaiming furnace. It is estimated that 50 tons of solids per day will be removed from the process water, of which 24 tons will be recovered as lime.

Recharge Program

The purpose of the advanced wastewater and desalting plants is to ultimately produce 30 mgd of high quality water for the salt water intrusion/groundwater replenishment injection system.

From the one MG reservoir, where chlorinated effluent, desalted seawater and/or deep well water are blended, the water will be pumped to the injection wells. Pumping is accomplished with three vertical turbine can-type injection pumps (one always on standby) with 400 HP variable speed drives. Each of these units is capable of pumping 5,000 to 7,200 gpm.

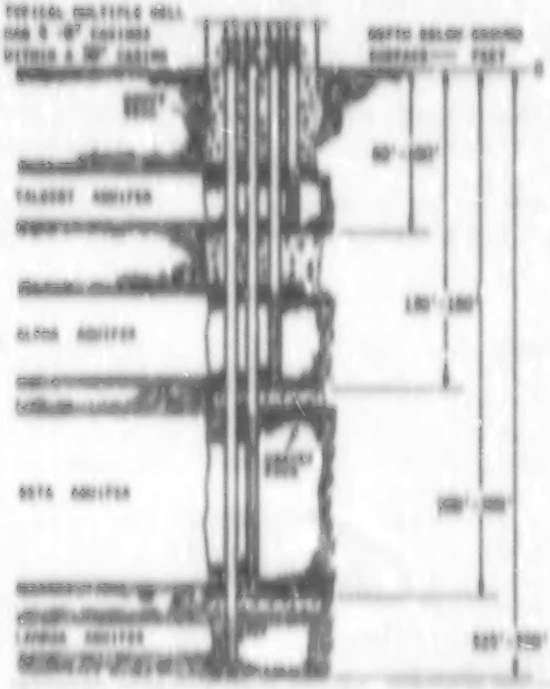
The water is pumped through a main distribution line at 80 psi to a series of 23 injection wells placed approximately every 600 ft along Ellis Avenue.

Figure A-8 shows a typical well cross-section with four six in. wells located within a 30 in. casing. Each six in. well penetrates to one of four separate aquifers from 80 to 350 ft below ground level.

A network of 170 water supply wells will aid in monitoring changes in the groundwater quality due to the injection program. Actually, the expected TDS concentration of the final recharge water, 550 mg/l, is only slightly higher than the average TDS of the groundwater (509 mg/l), while the hardness of the recharge water will be significantly lower than groundwater hardness, 100 mg/l vs. 274 mg/l. In addition, the new recharge water is substantially better in quality than the Colorado and Santa Ana River water

Table A-5. AVERAGE EFFLUENT CHARACTERISTICS AT THE ORANGE COUNTY SANITATION DISTRICT AND THE ORANGE COUNTY WATER DISTRICT WASTEWATER RECLAMATION PLANTS

Constituents	Characteristics (mg/l) Expected		
	OCSD Secondary Effluent	OCWD Tertiary Effluent	Blended Product Water
TDS	1300	1100	550
BOD	50	1	0
COD	150	10	5
Total Hardness	350	200	100
SS	50	1	0
Cl^-	240	240	125
Na^+	220	220	110
$SO_4^=$	250	250	125
Fe	--	0.6	0.3
NH_3	25	2.0	1.0



TYPICAL MULTIPLE WELL
DEPTH BELOW GROUND SURFACE — FEET
0
TALBERT AQUIFER
ALPHA AQUIFER
BETA AQUIFER
LAMBDA AQUIFER

FIGURE A-8

TYPICAL MULTI-CASING INJECTION WELL
AT ORANGE COUNTY

(TDS 700-800 mg/l) that has been used for percolation recharge since 1949. Therefore, it is anticipated that the new injection/recharge program will have no adverse effects on groundwater quality.

However, the recharge operation will be under close surveillance from both the State and Regional Water Quality Control Board and the State Health Department. Table A-10 summarizes the water quality requirements for the recharge water as stipulated by WQCB. The presence of the electrical conductivity or TDS limit has forced the water district to blend effluent and low TDS fresh water or desalinated water 50:50 in order to reduce TDS below the requirements.

In addition, the State Health Department has imposed a number of restrictive provisions and requirements to the program including, ". . . an alternate source of domestic water supply shall be provided any user whose groundwater is found to be impaired by the injection program."

Economics

Table A-11 shows the capital cost breakdown for the entire reclamation, desalination, recharge project. As can be seen, Orange County is responsible for approximately 37 percent of the total project cost. Table A-12 provides a further cost breakdown of capital and operation and maintenance costs at design 15 mgd flow. Amortized at 5.5 percent over a 25-year life, the annual capital recovery cost to the Water District alone is $620,000. Adding the anticipated annual operation and maintenance costs of $3,774,000 yields an annual cost to the District of $4,394,000 or an average of $668/MG. This breaks down to roughly $240/MG for the advanced wastewater treatment plant (15 MGD), $2,722/MG for the desalting facility (3 MGD), and $10/MG for the injection facilities (30 MGD). The total cost for the entire project including all grant monies is $827/MG (1972 $). It is important to note, however, that the very high anticipated O & M costs for the initial desalting operation, $2,730,000 per year for the 3 MGD facility, result because the present desalting module is basically an R & D vessel and, as such, will be used extensively in costly testing programs to optimize operation before expanding the facility. Authorities estimate that O & M costs under

Table A-10. SANTA ANA REGIONAL WATER QUALITY CONTROL BOARD QUALITY REQUIREMENTS FOR WATER RECHARGED TO THE SANTA ANA GROUNDWATER BASIN

Constituent	Max. Concentration (mg/l)
Ammonium	1.0
Na	110
Total Hardness	220
SO_4	125
Cl	120
Total N	10
Electrical Conductivity	900(1)
Hexavalent Cr	0.05
Cd	0.01
Se	0.01
Mn	0.05
Barium	1.0
Ag	0.05
Cu	1.0
Pb	0.05
Hg	0.005
As	0.5
Fe	0.3
Fl	0.8
B	0.5
MBAS	0.5

(1) μ mhs/cm

Table A-11. CAPITAL COSTS FOR RECLAMATION AND RECHARGE FACILITIES AT ORANGE COUNTY, CALIFORNIA [4]

	Cost ($1,000 1972 $)			
	Total	Federal[1]	State[2]	Local[3]
- Investigations and Improvements	2,070	118	--	1,952
- Wastewater Reclamation	10,920	6,006	2,730	2,184
- Injection Barrier Facilities	1,365	364	182	819
- Seawater Desalting Module	7,917	4,550	--	3,367
TOTALS	22,272	11,038	2,912	8,322

[1] Federal participation was through:
- Office of Saline Water, Department of the Interior
- Environmental Protection Agency

[2] State grant funds were made available through:
- State Water Resources Control Board

[3] Local financing was by:
- Orange County Water District

[4] All cost expressed as January 1972 $ (see Appendix B for capital cost factors)

Table A-12. ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS FOR THE WASTEWATER RECLAMATION/RECHARGE SYSTEM AT ORANGE COUNTY, CALIFORNIA (COST REFERENCE JANUARY 1972)

CAPITAL COST	Thousands of $
Wastewater Reclamation Plant	
Land	192
Influent Pipelines & Pump Station	310
Clarification	600
Ammonia Stripping	2,579
Recarbonation	347
Filtration	784
Granular Carbon Adsorption	2,751
Chlorination	320
Sludge Treatment	1,536
Blending & Storage Reservoir	214
Maintenance & Laboratory Bldgs.	218
Engineering	910
Miscellaneous	68
Total	10,920
Injection Barrier Facilities	1,345
Seawater Desalting Module	7,917

ANNUAL OPERATION & MAINTENANCE COST	Thousands of $
Wastewater Reclamation Plant	
Influent Pipelines & Pump Station	30
Clarification	120
Ammonia Stripping	254
Recarbonation	55
Filtration	75
Granular Carbon Treatment	105
Chlorination	50
Sludge Treatment	229
Total	998
Injection Barrier Facilities	46
Seawater Desalting Module	2,730

15 MGD desalting operations will be close to this initial $2,730,000 figure. When these costs are compared to the costs of imported water, filtered Colorado River water at $205/MG and filtered state water at 240/MG, it can be seen that the District is accepting a significant negative cost differential to produce a high quality recharge supply and preserve groundwater quality.

Future for Recharge Programs

Barring unforeseen problems, the 15 mgd OCWD tertiary treatment plant will produce reclaimed water for recharge for many years. However, due to the relatively high TDS concentrations of the source waters for the area and the fact that the community adds an incremental 200-300 mg/l TDS with each pass, the District is looking to a combination of seawater desalting and wastewater reclamation as the only way to effectively maintain proper TDS levels and protect the groundwater supplies over the long term.

SANTA CLARA VALLEY WATER DISTRICT (PALO ALTO AND SAN JOSE, CA)

Introduction

A significant portion (roughly 50 percent) of the water supply in Santa Clara County is derived from the underground resource. However, the groundwater supply has been in the past and may again in the future, be adversely affected by overdrafting. Lowered water tables have accelerated salt water intrusion in the Palo Alto-Los Altos-Mountain View area, which is the area most remote from future imported fresh water supplies.

Saline water intrusion has become extensive in the shallow aquifers of the region, and much of this water is now non-potable. The most important deeper (150 feet) aquifers, however, are endangered due to possible vertical migration of the salt water from these shallow, intruded basins. Heavy pumping of good quality water from the lower aquifers has ruduced their pressure and increased the possibility of salt water migrating vertically through the overlying protective clay layers.

In light of the fact that the present water supply will not be able to meet demands by 1978, it is especially important to protect the groundwater resource against contamination by intrusion. To do this, the water district has developed and designed an advanced wastewater treatment/groundwater recharge system.

The first phase of the program, due to go into construction in 1975, will consist of tertiary treatment of up to 4 mgd, of which 2 mgd will be injected and extracted from a line of parallel injection/extraction wells to form a hydraulic salt water intrusion barrier. Streamlines from each pair of injection/extraction wells, termed doublets, will effectively "block out" a segment of the groundwater basin and prevent inland migration of saline waters. Because of a developing recreational and landscaping need, additional treatment capacity of 2 mgd will be provided for production of reclaimed waters intended only for irrigation usage. Upon "flushing out" of the intruded saline waters, plans call for the eventual extraction of all the recharged water for irrigational or even industrial reuse.

Municipal Treatment

Figure A-9 shows a flow diagram of the proposed tertiary treatment plant due to go into construction following approval of plans and specifications. Tertiary treatment for the effluent to be used directly for irrigation will consist

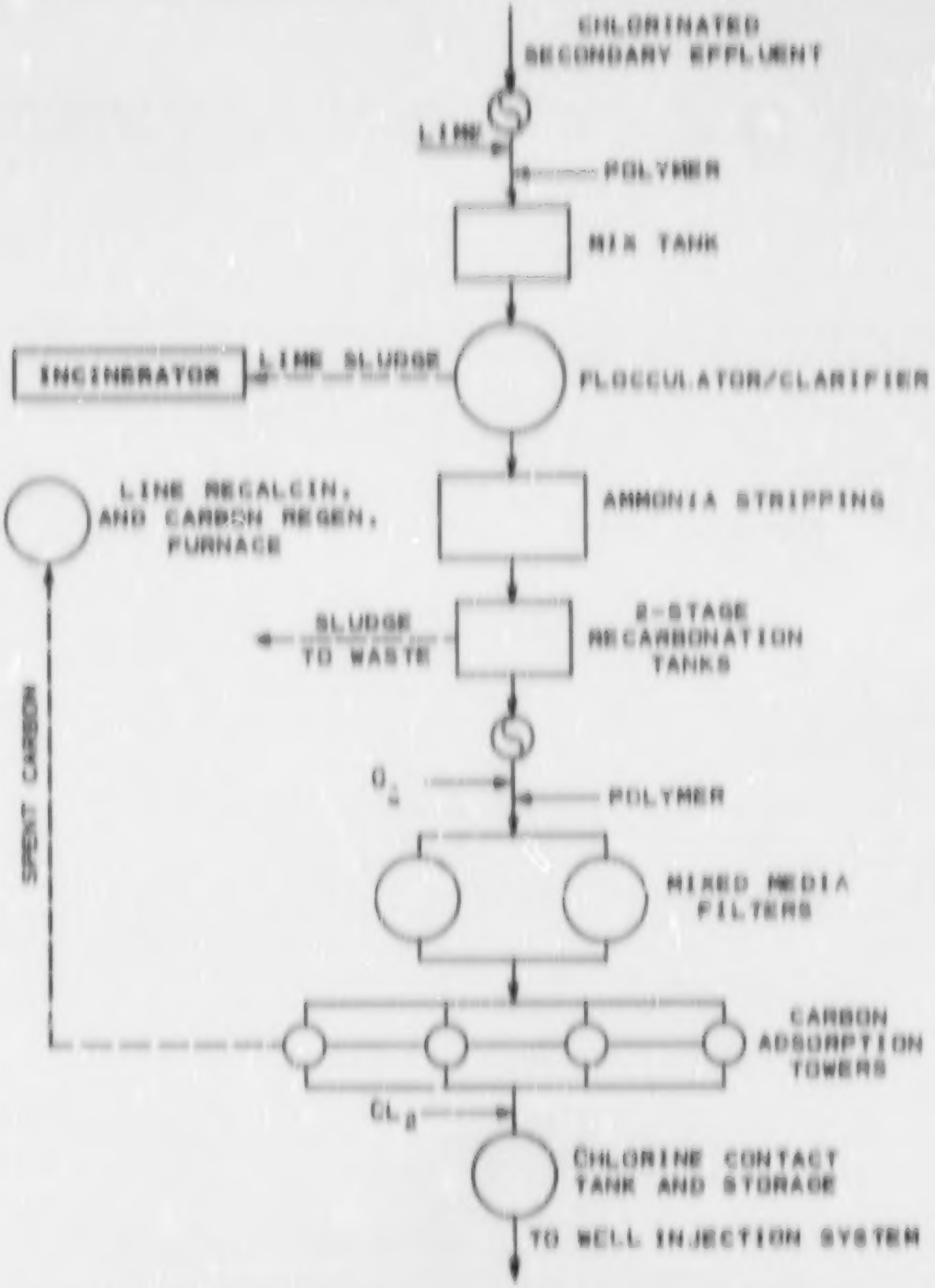

CHLORINATED SECONDARY EFFLUENT
LIME
POLYMER
MIX TANK
INCINERATOR
LIME SLUDGE
FLOCCULATOR/CLARIFIER
LIME RECALCIN. AND CARBON REGEN. FURNACE
AMMONIA STRIPPING
SLUDGE TO WASTE
2-STAGE RECARBONATION TANKS
SPENT CARBON
O_2
POLYMER
MIXED MEDIA FILTERS
CARBON ADSORPTION TOWERS
CL_2
CHLORINE CONTACT TANK AND STORAGE
TO WELL INJECTION SYSTEM

FIGURE A-9
PLANNED ADVANCED WASTEWATER
TREATMENT PLANT AT PALO ALTO

of filtration and chlorination only and will take place in a separate facility not shown in the figure.

The chlorinated secondary effluent is treated with both lime and polymer before entering a reactor clarifer that provides 30 minutes of flocculation and 120 minutes of settling for removal of suspended solids, heavy metals, and phosphorus

The highly alkaline water, now at pH 11, next enters the ammonia stripping surface aeration tanks where the release of ammonia gas to the atmosphere is enhanced by surface agitation. High pH provides the chemical conditions that maximize conversion of ammonium ions in solution to ammonia as dissolved gas.

The effluent then enters a three-chamber recarbonation tank. In the first chamber, the wastewater is neutralized by diffusing carbon dioxide gas, supplied by compressed stack gases from an existing sludge incineration facility, into the water. Provisions have also been made for future intermediate settling basin followed by second stage recarbonation. To widen the spectrum of trace organic removals, ozonation will be utilized following the recarbonation process. Flexibility is also provided to utilize ozonation following activated carbon.

The process stream is then given mixed media filtration to remove suspended solids and colloidal material, and to protect and prolong the life of the activated carbon. However, because of the stringent requirements to insure maximum recharge capabilities, the process is designed with the flexibility to provide filtration after activated carbon treatment or two stage filtration before and after carbon adsorption. The two filters will be operated at a four gpm/ft^2 hydraulic loading rate.

The water is then pumped through four carbon towers that provide a 34 minute contact time for the adsorption of organics reducing the COD. These columns will be piped to permit operation of the individual beds in series, or in parallel. In addition, chlorination after the first two carbon columns is possible when the towers are operated as four in a series. This sequence will permit the second two carbon columns to perform the added function of residual chlorine removal.

Effluent from the carbon adsorption process flows to the chlorine flash-mix basin and into the contact basin. The 80 minute detention time in the chlorine contact basin storage tank will provide sufficient chlorine and retention time to practice break-point chlorination for disinfection and stripping of residual ammonia. Chlorination to a free residual (HOCl) of one mg/l held for 60 minutes should assure complete inactivation of all virus.(1)

The effluent will then be pumped to the injection well system.

Solids handling at the treatment plant will include carbon regeneration in a multi-hearth furnace. Lime sludge will initially be incinerated with recalcining being evaluated as a future addition.

Important features of the plant include the ability to choose a variety of unit process combinations and to by-pass any individual element due to piping system design.

Anticipated quality of the effluent from the tertiary treatment plant is summarized in Table A-13. This water for recharge is expected to meet current drinking water standards.

Recharge Program

The proposed reclamation facility capacity is four mgd, two mgd for groundwater recharge and two mgd for direct irrigation use.

The complete recharge/reuse system is diagrammed in Figure A-10. As shown, the ultimate goal (1979) is to inject the two mgd of tertiary effluent into shallow aquifers and then to extract the recharged water for irrigation reuse without allowing it to commingle with native groundwater used for potable supply.

The initial effect of injection into the shallow, non-potable, salt water intruded aquifers will be to establish a pressure barrier against further intrusion and to flush the high salinity water out the extraction system, thus gradually replacing and improving the quality of the water in those aquifers. After an initial period of operation, it

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(1) Taken from Eliassen, Rolf, Environmental Safeguards for Control of Viruses in the Proposed Wastewater Reclamation Plant of the Santa Clara Valley Control & Water District, Palo Alto, CA, 1974.

Table A-13. ANTICIPATED TERTIARY EFFLUENT QUALITY CHARACTERISTICS AT PALO ALTO, CALIFORNIA

Constituent	Maximum Concentration (mg/l)
BOD	1
COD	10
Suspended Solids	0.1
Turbidity (JTU)	0.1
MBAS	2.2/100 ml
Coliform (MPN)	5-15
Ammonia	850
TDS	350
Chlorides	0.05
Arsenic	0.1
Barium	1.02
Cadmium	0.05
Chromium (+6)	0.3
Copper	0.2
Lead	0.05
Manganese	0.05
Selenium	0.01
Silver	0.03
Zinc	1.0
Mercury	0.005
Phosphate	1

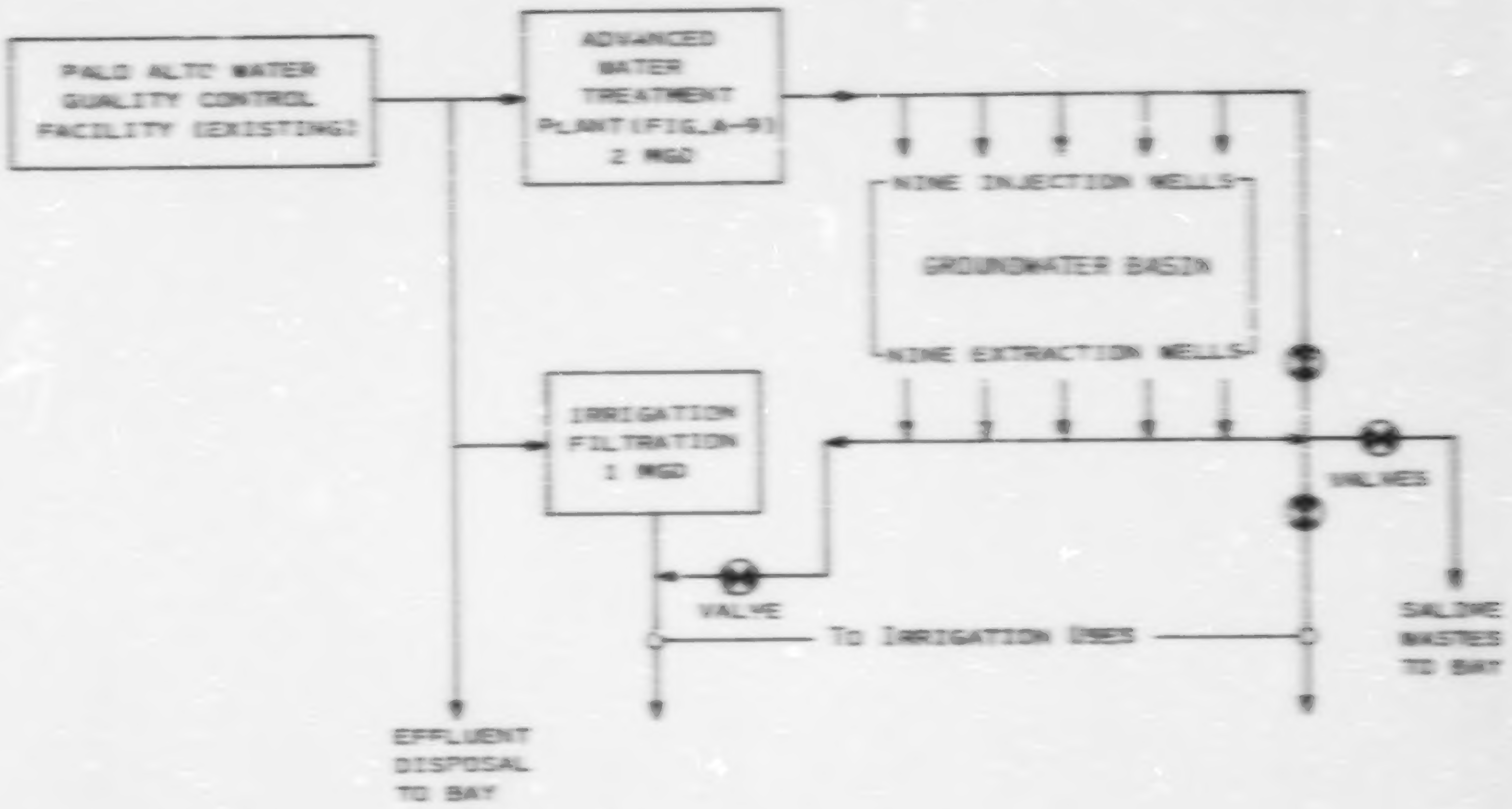
PALO ALTO WATER QUALITY CONTROL FACILITY (EXISTING)
ADVANCED WATER TREATMENT PLANT (FIG. A-9) 2 MGD
NINE INJECTION WELLS
GROUNDWATER BASIN
NINE EXTRACTION WELLS
IRRIGATION FILTRATION 1 MGD
VALVE
VALVES
TO IRRIGATION USES
EFFLUENT DISPOSAL TO BAY
SALINE WASTES TO BAY

FIGURE A-10
PROPOSED WASTEWATER RECLAMATION/REUSE SYSTEM
AT PALO ALTO, CALIFORNIA

is anticipated that the intruded groundwaters will have been replaced with the recharge water, and that when extracted, this reclaimed water will be suitable for use in unrestricted irrigation. None of the treated effluent will be used to replenish potable aquifers.

The nine injection and nine extraction wells will be similar in construction to the test well used for experimentation between August & November, 1974, except that only two PVC casings will be used. One will terminate in the 20 foot aquifer, the other will extend into the 45 foot aquifer. Figure A-11 provides a detail of the original well features. The drill hole was 24 inches in diameter and housed three six-inch diameter casings, one to each of the three aquifers (20 ft, 45 ft, and 185 ft deep). The two shallow aquifers, both invaded by seawater, were separated from the deep high quality aquifer by an extensive clay aquiclude, while the aquitard material separating the 20 and 45 foot aquifer was of the "leaky" type which provided a vertical path for hydraulic connection between the aquifers.

Three test hole-observation wells, located at various distances and directions from the injection/extraction well, were used to monitor the pumping and injection tests. The injection tests were conducted with potable Palo Alto water supply to yield information concerning the aquifer characteristics and confirm the relationships between aquifers in response to pumping and injection. Authorities feel that the treated effluent will be of high enough quality to perform in a similar fashion under recharge conditions. It should be noted, however, that this may not always be the case. In similar injection tests at Mineola, New York (see Long Island, New York case study in Appendix A), utilizing a similar quality tertiary effluent to that anticipated at Palo Alto, it was shown that very minor concentrations of certain components in the final effluent stream (iron, phosphate, turbidity) caused clogging problems in the injection well. Naturally, the characteristics of the aquifer will determine acceptable quality limits for successful operation.

The test program demonstrated the following:

- Injection into the 45 ft aquifer is a feasible method of creating the hydraulic changes necessary to control seawater intrusion.
- Injection into the 45 ft aquifer resulted in a reduction in chlorides in the 20 ft aquifer.

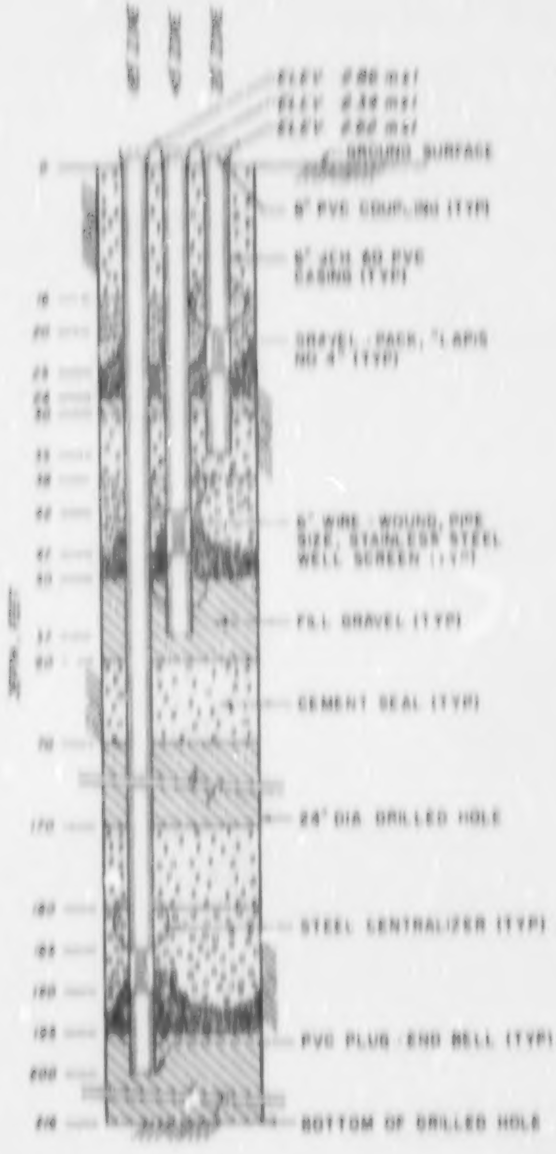
ELEV
ELEV
ELEV
GROUND SURFACE
8" PVC COUPLING (TYP)
8" SCH 80 PVC CASING (TYP)
GRAVEL PACK, "LAPIS NO 4" (TYP)
6" WIRE-WOUND, PIPE SIZE, STAINLESS STEEL WELL SCREEN (TYP)
FILL GRAVEL (TYP)
CEMENT SEAL (TYP)
24" DIA DRILLED HOLE
STEEL CENTRALIZER (TYP)
PVC PLUG-END BELL (TYP)
BOTTOM OF DRILLED HOLE
DEPTH, FEET
0
170
200

FIGURE A-11

DETAIL OF INJECTION/EXTRACTION WELL FEATURES

- The spacing between the injection well and the extraction well in a particular doublet should be approximately 1,000 ft, the pumping rate should be approximately 150 gpm for each well, and the injection pressure should be no more than 20 psi.
- The critical spacing between doublets as anticipated is approximately 1,800 ft. The spacing to be used for design purposes, however, is conservatively established at 1,000 ft.

Economics

Table A-14 summarizes capital costs (in 1972 $) for the tertiary treatment plant and injection/extraction system.

Table A-15 summarizes estimated operation and maintenance costs for the treatment plant and barrier system. The costs are based on year-round operation, and are referrenced to Jan. 1972.

Due to federal ano state grants, the Santa Clara Valley Water District is only required to provide 12-1/2 percent of the total project capital costof $2,444,000 or $306,000. Adding $143,000 for transmission pipelines to ultimate irrigation users, the total annual capital recovery cost would be $193,000 of which the Water District's share would be $33,000 (5.5 percent interest and 25 year life). Assuming year-round operation, the total annual cost, including O and M, would be $183,000 (1972 $) to the Water District and $343,000 for the project as a whole.

Since full-year operation would produce an average of 3 mgd for irrigation, the cost to the Water District breaks down to $167 per MG.

A major portion of this cost (approximately $130 per MG) will be recovered by the District through sale of the reclaimed water for irrigation.

Future for Recharge Program

The Santa Clara Valley Water District hopes to realize the following benefits from its proposed system:

- To restore the shallow groundwater aquifers presently degraded by intruding salt water, and to protect deeper high quality aquifers from future contamination;

Table A-14. ESTIMATED CAPITAL COSTS FOR WASTEWATER RECLAMATION/RECHARGE SYSTEM AT PALO ALTO, CALIFORNIA

Element	$1,000 (Jan. 1972)	
Clarifier-Flocculator	240	
Filters	300	
Carbon Adsorption System	510	
Main Structure and Appurtenances	730	
Subtotal - Treatment Facility		1,780
Well System (9 pairs)	290	
Power Supply and Controls	80	
Subtotal - Barrier		370
Total Construction Cost		2,150
Technical Services	210	
Legal, Fiscal, and Administrative	4	
Contingencies	80	
TOTAL		2,444

Table A-15. ESTIMATED ANNUAL OPERATION AND MAINTENANCE COSTS AT PALO ALTO, CALIFORNIA

Item	$1,000 (Jan. 1972)
Administrative and Fixed Charges	7
Salaries	36
Power and Utilities	28
Lime	29
Act. Carbon	7
Chlorine	23
Repair and Maintenance	6
Miscellaneous	9
	$ 145
Barrier System	5
Total	$ 150

- To reclaim wastewater and reuse it so as to conserve precious fresh water supplies;
- To gain extensive knowledge into the art of wastewater treatment, recharge, and recovery for reuse.

If extensive monitoring of the planned "Phase I" system herein described shows positive results, authorities anticipate further expansion of the barrier system and perhaps eventual direct replenishment of the deep, high water quality, aquifer with tertiary wastewater.

U.S. WATER CONSERVATION LABORATORY (PHOENIX, ARIZONA)

Introduction

In 1967, an experimental high-rate land treatment system called the Flushing Meadows project (partially funded by EPA) was installed by the U.S. Water Conservation Laboratory and Salt River Project in the Salt River bed west of Phoenix, Arizona. The purpose of the project was to study the feasibility of renovating secondary effluent for unrestricted irrigation, recreation, and certain industrial uses.

Extensive use of groundwater supplies by agriculture and an increasing population have created an overdraft situation, such that the groundwater levels in some parts of the valley have been dropping at ten ft per year. To aid in conserving the groundwater resource, authorities are initiating reclaimed wastewater reuse programs to reduce the demand for groundwater. By the year 2000, the wastewater flow from Phoenix and adjacent cities is expected to reach 250 mgd which, if reused, could irrigate nearly 70,000 acres (more than the projected remaining agricultural land in the area), while leaving a portion for recreational lakes, industry, and other uses.

To permit large-scale reuse of wastewater in the Salt River Valley, the effluent should meet the requirements for "unrestricted" irrigation and recreation. One possibility for obtaining the necessary quality improvement of conventional secondary effluent is by land treatment with high-rate infiltration basins in the bed of the Salt River. The purpose of the Flushing Meadows project was to evaluate the feasibility of such a system.

Municipal Treatment

The 91st Avenue sewage treatment plant in Phoenix is a step aeration, spiral flow, activated sludge plant treating 80 mgd.

Table A-15 summarizes typical effluent characteristics from the plant.

Recharge Program

The Flushing Meadows project is located about 1.5 miles downstream from the 91st Avenue wastewater treatment plant.

The project, which was put into operation in September, 1967, consists essentially of six horizontal basins, 20 x 700 ft

Table A-16. TYPICAL MUNICIPAL EFFLUENT CHARACTERISTICS AT THE 91ST AVENUE PLANT, PHOENIX, ARIZONA

Constituent	Concentration (mg/l)	Constituent	Concentration (mg/l)
BOD	15	Na^+	200
COD	45	Ca^{++}	82
SS	20-100	Mg^{++}	36
TDS	1,100	K^+	8
TOC	20	HCO_3	381
NH_4-N	30	Cl^-	213
NO_3-N	1	SO_4	107
NO_2-N	2	PO_4	30
Org. N.	3	CO_3	0
E. Coli/100 ml	10^6		

each, spaced 20 ft apart. Figure A-12 shows a plan view of the recharge site. Secondary effluent is pumped from the effluent channel into these basins with the rate of flow into each basin recorded with a critical depth flume.

Shallow gravel dams were placed across the basins approximately 50 ft from the inlets to form small sedimentation basins to reduce occasional high SS concentrations in the effluent. Water depths in the basins are controlled by outlet/overflow structures and overflow was measured with critical-depth flumes so that other parameters could be evaluated without interference from varying water depths.

Table A-17 provides a soil profile from two wells in the basin area. The profiles indicate an irregular succession of coarse sand and gravel layers, with an impermeable clay boundary at 247 ft.

This soil profile is favorable for rapid infiltration because of its basic coarse sand nature allowing high percolation rates, and because the finer material is on the surface, thus confining clogging phenomena to the upper layer where it can most easily be controlled.

Of the several flooding techniques and the different surface covers used (earth, vegetation, and gravel), it was determined that maximum hydraulic loading rates were obtained with bare soil basins and flooding periods of about 20 days alternated with drying periods of ten days in the summer and 20 days in the winter. The maximum infiltration rate achieved with a 1 foot water depth in the basins was roughly 400 ft/yr. Higher rates may be obtained by increasing the water depth by several feet. For optimum nutrient removal, however, the infiltration rate should be lowered to around 300 ft/yr as explained below.

By proper management of the system, nutrient removal by the soil can be maximized. At Flushing Meadows, this was best achieved by using flooding periods of about ten days and drying periods of two weeks. With this schedule, oxygen was soon depleted in the soil during flooding causing nitrogen, in the ammonium form, to be absorbed by the clay and organic particles. Flooding was terminated before the cation exchange complex in the soil was saturated with ammonium. Upon drying, oxygen entered the soil and ammonium was nitrified under aerobic conditions to nitrate. Concurrently, some of the nitrate formed was denitrified in micro-anaerobic pockets in the otherwise aerobic upper soil zone to nitrogen gas that escaped to the atmosphere. When flooding was resumed, if the basins were immediately flooded to a depth above one ft, the nitrates were quickly leached out of the

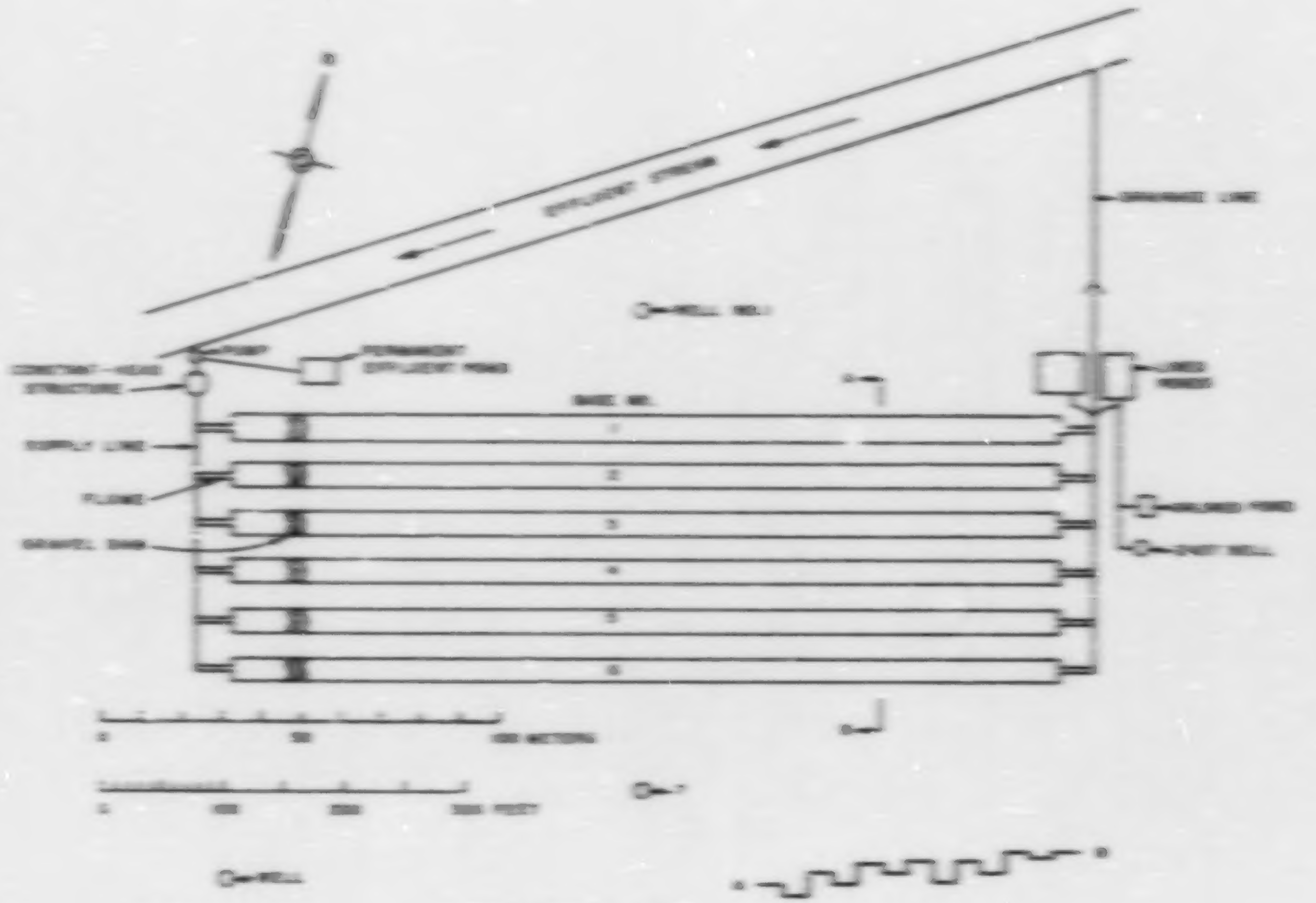
N
EFFLUENT STREAM
DRAINAGE LINE
WELL NO.1
PUMP
PERMANENT EFFLUENT POND
CONSTANT-HEAD STRUCTURE
LINED PONDS
BASIN NO.
1
2
3
4
5
6
SUPPLY LINE
FLUME
GRAVEL DAM
HOLDING POND
EAST WELL
A
A
0
50
100 METERS
0
100
200
300 FEET
WELL
A
B

FIGURE A-12

PLAN OF FLUSHING MEADOWS PROJECT

Table A-17. SOIL PROFILES AT FLUSHING MEADOWS

East Well		West Center Well	
Depth (ft)	Material	Depth (ft)	Material
0-3	Fine loamy sand	0-3	Fine loamy sand
3-27	Sand, gravel, and boulders	3-33	Sand and gravel
27-30	Clean sand, gravel, and boulders	33-44	Boulders and gravel
30-49	Clean, fine sand with occasional cobbles	44-50	Sand and gravel
49-81	Clean, fine sand with occasional thin gravel strata	50-57	Sand and traces of clay
81-123	Clean, fine sand	57-63	Coarse, clean gravel
123-126	Fine sand with trace of clay	63-72	Sand, gravel, traces of clay
126-136	Clean, fine sand	72-86	Coarse gravel and boulders
136-146	Clean sand and gravel	86-98	Sand, gravel, and traces of clay
146-197	Clean, fine sand	98-100	Fine sand
197-200	Fine sand and gravel		
200-247	Fine sand		
247	Start of clay layer		

Note: Ft x 0.3048 = m.

top few feet of soil to the groundwater. However, if initial flooding was shallow (a few inches deep), the lower head allowed a lower infiltration rate, larger nitrate retention time in the microbiologically active soil zone, and further denitrification. At these lower initial hydraulic loading rates, nitrogen removals were as high as 80 percent, whereas if high rates are consistently maintained, nitrogen removal was only 30 percent with a peak nitrate surge to the groundwater after the start of a new flooding cycle.

Essentially no nitrogenwas removed if short, frequent flooding periods (two days flooding, five to ten days drying) were used. Apparently, the flooding cycle was not long enough to allow oxygen depletion in the soil; thus aerobic conditions dominated, and all ammonium was nitrified to nitrate, which was then leached to the groundwater.

The flooding schedule and desired infiltration rates for maximizing denitrification in a high rate system depend on several factors: soil cation exchange capacity, ammonium exchange percentage, the form and concentration of the nitrogen in the wastewater, the oxygen diffusion rate into the soil, the temperature, and other factors. Therefore, authorities cautioned that each recharge situation is somewhat unique and a proper flooding schedule must be developed accordingly.

Phosphorous removal at Flushing Meadows was found to be basically dependent upon the distance traveled through the soil. The chief removal mechanism wasprecipitation as calcium phosphate or magnesium ammonium phosphate. Underground travel distances of 30 ft produced a 50 percent reduction, and distances of several hundred feet were found to be sufficient for a 90 percent phosphorous removal.

At the Flushing Meadows project, fecal coliforms were reduced from about 10^6 to generally less than 200 per 100 ml after 30 ft of downward percolation. Additional lateral movement reduced the coliform density to generally less than ten per 100 ml after 100 ft and to zero after 300 ft.

Virus studies were performed bi-monthly in 1974 to determine the fate of virus in the soil system.
No virus has been detected in the renovated water sampled at depths of 20 ft and 30 ft below the basins. The mechanism of removal appears to be one of adsorption and is governed by the same factors as ion exchange.

Economics

The economic costs summarized in Table A-18 are those projected for the 15 mgd full-scale recharge/extraction system detailed in the following section. The main capital costs are for the extraction well system. The largest portion of the operating costs go toward operation of the well pumps. The system would be comprised of four ten-acre rectangular basins with three extraction pumps located on the center berms.

The total capital cost of $212,000 (January 1972 $) represents an annual capital recovery cost of $16,000 at 5.5 percent interest and 25-year life, or $2.9/MG at 15 mgd. Adding the operation and maintenance costs of $28,000/yr, the total annual cost becomes $44,000 or approximately $8/MG. This figure is a small fraction of the cost to treat secondary effluent in-plant to provide a similar quality water.

Future for Recharge Program

The City of Phoenix, with funds supplied through an EPA grant, has completed construction of a 15 mgd wastewater recharge/extraction facility in Phoenix, Arizona. The first well was to be in operation by 1975. The project is a first step towards extensive wastewater renovation and reuse for unrestricted irrigation, and ultimately for a large green belt recreational zone and nuclear power plant cooling water. Irrigation, and recreation reuse water must meet the following standards: $BOD_5 \leqslant 5$ mg/l, $SS \leqslant 5$ mg/l, and fecal coliform $\leqslant$ 200/100 ml. Authorities estimate that the renovated water should be well within required limits for this use. Industrial reuse will most likely require further treatment at the plant site as required by the specific use.

Figure A-13 on page 102 shows a schematic diagram of the 15 mgd recharge/reclamation system. Secondary effluent from the 23rd Avenue plant will flow through an open concrete channel to an 80-acre pre-sedimentation pond for settleable solids removal and furthur polishing. The effluent will then be discharged through gate valves into the loamy sand and gravel spreading basins. The basins will be managed to achieve maximum nitrogen removal as detailed previously with two of the basins being flooded while the other two are in the drying cycle. Expected infiltration rates are about 400 ft per year.

The basins will be equipped with discharge gate valves to rapidly drain the basins after the inflow is stopped, thus

Table A-18. ESTIMATED CAPITAL AND OPERATION & MAINTENANCE COSTS OF 15 MGD RECHARGE - EXTRACTION SYSTEM AT PHOENIX, ARIZONA

Capital Costs		$ 1,000 (1972)
. Land acquisition (1)		0
. Construction of basins & effluent distribution system		35
. Extraction wells & discharge system (assuming 3 wells @ $44,000 each)		177
	Total	$ 212

Operation & Maintenance Costs		$ 1,000 (1972)
. Maintenance of basins, etc.		7
. Extraction well operation (based on power costs of $0.018/acre/ft/ft of lift and 100 ft of total lift)		21
	Total	$ 28

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(1) City of Phoenix already owns land to be used in project (estimated value of the land is roughly $1,780/acre or $71,000 total (1972 $).

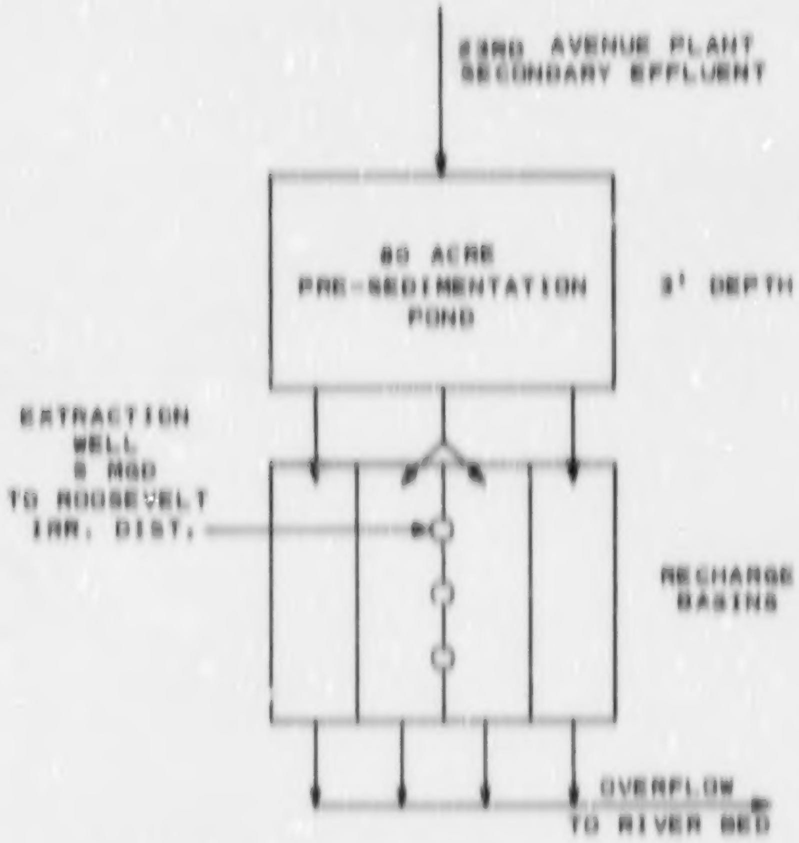

23RD AVENUE PLANT
SECONDARY EFFLUENT
80 ACRE
PRE-SEDIMENTATION
POND
3' DEPTH
EXTRACTION
WELL
8 MGD
TO ROOSEVELT
IRR. DIST.
RECHARGE
BASINS
OVERFLOW
TO RIVER BED

FIGURE A-13
15 MGD WASTEWATER RECHARGE/EXTRACTION
SYSTEM AT PHOENIX, AR.

accelerating the drying cycle. This overflow is discharged to a dry riverbed.

Three extraction wells, located along the center berm, will be used to recapture all the recharged effluent for unlimited irrigation at the Roosevelt Irrigation District. Each well will be approximately 200 ft deep with the last 100 ft perforated. The wells will extract an average of 3,500 gpm each of a total of approximately 15 mgd. The water will initially be pumped through a 24 in., asbestos-cement pipeline to the irrigation district.

One of the important concepts of this system is that no significant amount of recharged effluent will mix with the native groundwater causing possible degradation of that fresh water source. All recharged water will be extracted and the underground flow controlled so that a very slight gradient will exist toward the recharge basins, making it impossible for renovated water to move out into the aquifer. Figure A-14 shows a profile through the recharge/ extraction zone. Note that the water table drops toward the well, thus causing a gradient in the aquifer toward the extraction point.

It should be noved that ultimately the extracted water will reach the groundwater when reused for irrigation. However, the low hydraulic loading rates of irrigation operations, fine particle composition and higher clay content of the soil, mineral uptake by the plants, and other soil treatment mechanisms, will provide extensive additional treatment to the water before it reaches the groundwater table. The only danger of groundwater degradation after this second passage through the soil is the unavoidable TDS buildup in the percolate due to the large evaporation and transevaporation losses during irrigation.

An extension of this 15 mgd recharge/reuse project is currently being planned in Phoenix (Rio Salado Project) that would involve extensive recharge and extraction to renovate wastewater for use in a large green belt recreation zone. The green belt will follow the Salt River bed through Phoenix and will involve a series of lakes, parks, riding trails, and picnic areas.

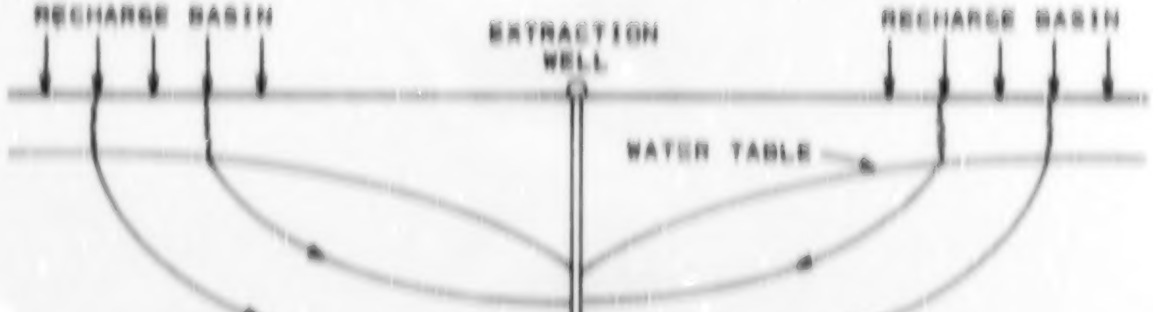

RECHARGE BASIN
EXTRACTION WELL
RECHARGE BASIN
WATER TABLE
IMPERMEABLE LAYER

FIGURE A-14
CROSS-SECTION OF TWO PARALLEL INFILTRATION STRIPS WITH WELLS MIDWAY BETWEEN STRIPS FOR PUMPING RENOVATED WATER

THE CITY OF SAN CLEMENTE, CALIFORNIA

Introduction

Throughout the 1950's and 1960's, salt water intrusion into the main aquifer at San Clemente (supplying 1/3 of the city supply) had been growing increasingly significant, and authorities feared the loss of the entire basin to intrusion. Therefore, in March, 1968, an agreement was entered with the United States Marine Corps to percolate reclaimed water into the San Mateo River Basin on Camp Pendleton. These recharged waters were to act as a salt water barrier to protect the underground resources of both the city and the base, and to serve as irrigation water for the base after extraction.

Since the recharge program has been in operation, the trend of increasing salinity in the San Clemente supply well water has been reversed

Domestic Treatment

The city of San Clemente operates one tertiary treatment plant that treats an average of 2.3 mgd (plant capacity is four mgd to provide for future growth).

The plant includes conventional activated sludge treatment followed by 30 minutes of chlorination and dual media filtration. The two gravity filters are each 22 ft in diameter, fifteen ft deep, and capable of treating 700 gpm. The filters are comprised of one ft of 0.9 mm anthrafilt over one ft of 0.5 mm sand. At a five ft head loss, the units are automatically backwashed. The final effluent enters a sump pump for distribution to recharge, irrigation, or ocean disposal.

Table A-19 summarizes typical final effluent characteristics.

Recharge Operation

Figure A-15 shows a schematic diagram of the recharge facilities.

From the final sump tank, the effluent is pumped 3.5 miles by two 1,750 gpm pumps in a 12 in line. If the pipeline is unable to handle the entire volume, the overflow is discharged through the ocean outfall. Two booster pumps transport the water uphill to a holding pond with approximately 43 acre-ft of capacity. From this holding pond, an average of 0.3 mgd is pumped for golf course irrigation and 2 mgd is gravity fed through a pipeline to the spreading area in the San Mateo River Basin.

Table A-19. TYPICAL EFFLUENT CHARACTERISTICS AT SAN CLEMENTE, CALIFORNIA

Constituent	Concentration (mg/l)	Constituent	Concentration (mg/l)
BOD_5	4	Zn	0.05
SS	3	Cr	0.05
Total Hardness	350	Pb	0.05
TDS	1100	Cu	0.05
PO_4 as PO_4	45	Ni	0.05
NO_3 - N	14	Cd	0.05
		B	1.0
Na	225	Coliform/ 100 ml	2.2
Fl	0.6		

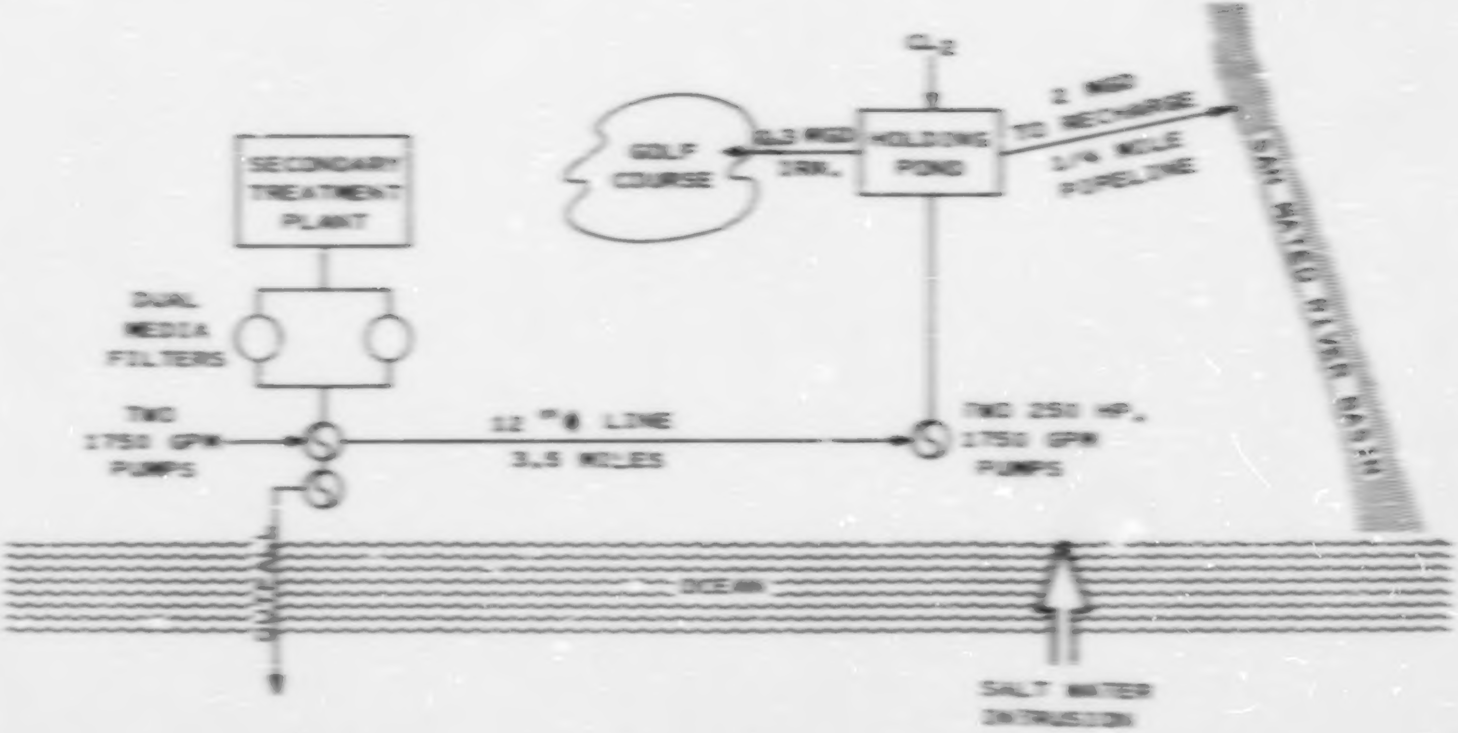

SECONDARY TREATMENT PLANT
DUAL MEDIA FILTERS
TWO 1750 GPM PUMPS
12 "Ø LINE
3.5 MILES
GOLF COURSE
0.3 MGD IRR.
HOLDING POND
Cl_2
2 MGD TO RECHARGE
1/4 MILE PIPELINE
SAN MATEO RIVER BASIN
TWO 250 HP, 1750 GPM PUMPS
OUTFALL
OCEAN
SALT WATER INTRUSION

FIGURE A-15
SCHEMATIC DIAGRAM OF RECHARGE
FACILITIES AT SAN CLEMENTE, CALIFORNIA

The flooding basin is simply a five-acre dyked area in the dry riverbed consisting of coarse sand and gravel. The infiltration rate is very high, roughly five to ten ft per day, and the effluent is continuously discharged to the riverbed where it percolates immediately.

The recharged water migrates downstream toward the ocean where it intercepts intruding salt water and forces it back toward the shoreline.

Although the exact course of the recharged water migration is not known, city authorities speculate that a small portion of this water is mixing with the native aquifer supply and is subsequently being extracted for domestic use.

Economics

The major cost of the recharge system is the long pipeline and pumps to transport the water from the plant to the recharge area. The estimated capital cost for pipeline and pumps was $200,000 in 1957 ($350,000 in January, 1972 $). Costs for tertiary treatment, two dual media filters, is the equivalent of $61,000 in 1972 dollars. Total capital cost for recharge facilities of $411,000 amortized at 5.5 percent for 25 years results in an annual capital recovery cost of $31,000.

Operation and maintenance requirements are very minimal, estimated at two man-hours per day on the average for checking pipelines and fixing periodic breaks, etc. Assuming a labor cost of $5 per hour, the annual O and M cost just for recharge operations is roughly $3,600.

Thus, the total cost of the recharge facilities is approximately $35,000 or, at a flow of 2.3 mgd, $42/MG.

Sale of 0.3 mgd of this water for golf course and state highway landscape irrigation brings an annual revenue of roughly $20,000 to the city. At present, no revenue is generated through the recharge operation.

Future for Recharge

By the end of 1976, authorities in San Clemente hope to implement construction to increase treatment plant capacity to eight mgd. In addition to current tertiary filtration, a portion of this water will be demineralized by ion exchange techniques and remixed with the rest of the effluent to lower overall TDS to 700 mg/l.

The final effluent will then be piped directly inland several miles (via a $1.1 million pipeline) and recharged in the Christianitis Canyon River Basin. At this point, the recharged water will percolate to great depths in the sand and gravel profile and slowly migrate downstream to the San Mateo River Basin aquifer and ultimately to the present recharge site.

The long distances and time involved in underground travel, as well as the in-plant demineralization, will ensure very high quality water fur recharge and ultimate extraction and reuse.

ST. CROIX, VIRGIN ISLANDS (GOVERNMENT OF THE VIRGIN ISLANDS)

Introduction

In 1971, the government of the U.S. Virgin Islands (Division of Environmental Health) and the federal Environmental Protection Agency co-sponsored a project on the island of St. Croix to demonstrate the feasibility of using highly treated wastewater for artificial recharge of potable groundwater basins.

St. Croix is the largest of more than 50 islands and cays which comprise the Territory of the U.S. Virgin Islands. It is 84 square miles in area and in the past 10 years has shifted from a rural agricultural economy to an island which is oriented toward tourism and industry. With this shift there has been a rapid increase in population and a rise in the standard of living on the island. Along with these changes has come a massive increase in water consumption so that the traditional sources of supply, rainwater collected in cisterns and well water, have proven inadequate for the populace. The continued consumer demand has been met, in a large part, by the use of desalinization plants for the conversion of seawater into fresh water.

The source of public water is now divided fairly evenly between groundwater, water derived from the Water and Power Authority (WAPA) desalinization plant in Christiansted, and water purchased from the desalinization plant operated by the Martin-Marietta Alumina Company (the latter soon to be phased out).

The purpose of the groundwater recharge project is to produce a high quality effluent and percolate it into the potable aquifers on the island. In this way, the yields of the wells in the area will be improved, and the recharged water will assist in preventing further seawater intrusion which is currently threatening one of the government's major well fields on the island. Hopefully, this wastewater reuse program will result in a lower demand for desalinated water and a subsequent drop in water costs now at $4/1,000 gallons.

Municipal Treatment

Wastewater from many parts of St. Croix flows initially into the primary treatment plant located at the western end of the Water Pollution Control complex at Estate Bethlehem Middle Works. Primary effluent (roughly 0.75 MGD) is discharged to the ocean through a 48 inch outfall sewer. As part of the recharge project, a weir on the outfall diverts 0.1 to 0.5 MGD into a lift station where it is pumped to the advanced wastewater treatment plant.

The plant employs secondary and tertiary treatment processes. Secondary treatment consists of completely mixed extended aeration activated sludge treatment using surface aerators, followed by conventional secondary clarification. Tertiary facilities include a solids contact or chemical flocculation unit and multi-media filtration. The solids contact unit uses an alum chemical feed to induce coagulation/flocculation and aid in solids removal by the filters. The two mixed media filters are operated in parallel and use anthracite coal, silica sand, and garnet sand as media. The final effluent is chlorinated before transmission to the spreading basins.

Typical quality characteristics of the water for recharge are as follows: BOD = 12 mg/l, turbidity = 1 to 3 JTU, TDS = 1,000 mg/l, chlorides = 400 mg/l, and coliform MPN = 0. Heavy metals are not significant. The high TDS results from the use of saltwater for toilet flushing on parts of the island. It is anticipated that once this practice has been stopped, that the TDS concentration of the recharge water will drop.

Recharge Program

Initial recharging operations commenced upon completion of treatment and percolation basin facilities in February, 1974. Testing continued until November, 1974, when the spreading ponds and portions of the island's wastewater collection systems were severely damaged by a flood. Currently, the facilities have been repaired and are in operation.

Final effluent from the plant is pumped 9,000 ft through a 6 inch ductile iron pipe to 100,000 gallon storage tank and the recharge area. The major recharge facilities consist of six spreading basins each with a surface area of 7,500 sq. ft.

The recharge area consists basically of geologically recent alluvial deposits up to 70 ft thick laid down on top of a lower Miocene formation. Spaced within the alluvial clays are thin horizontal aquifers of clay, sand, and gravel material. These aquifers are usually no more than 5 ft thick and are not interconnected except in the vicinity of supply wells. The upper 18 inches of soil is a dark clay with the subsequent lower material being lighter in color and containing a higher percentage of silt and sand. The upper clay layer was removed to expose the more porous lower horizons and enhance percolation. Bermuda grass is being grown in the basins to stabilize the soil and to aid in maintaining infiltration rates. It is hoped that the grass will utilize a portion of the nutrients contained in the recharge water, and that these nutrients will thus be removed when the grass is harvested.

The silt, sand, and clay soil in the recharge area had an infiltration rate of about 1-2 ft per day during the first nine months of operation. The optimal flooding schedule is just being established. Initial runs have established that a flooding period of 15 to 20 days followed by 30-40 days of drying can be successful.

Monitoring is achieved by using wells drilled in the area of recharge activity. Samples are taken from these wells and analyzed in the project area for chlorides, conductivity, calcium, total hardness, nutrients, BOD, coliforms, and other constituents. These initial results will provide background concentrations to aid in tracing the subsurface movement of the recharge water once full scale operations resume. Presently, the recharged water enters a semi-confined aquifer where it is highly diluted by existing groundwater. A significant change in groundwater quality has not been monitored to date.

Economics

Economic conditions on this island lend themselves to the reuse of wastewater, as potable water is scarce and at least two-thirds of the island's domestic supply is derived from distillation of seawater. The remainder comes from groundwater and rainwater catchments. Potable water is sold to the public for $4/k gal. by the Territorial Government which loses money even at that price.

Costs for the tertiary treatment and recharge facilities were not available, but authorities estimate the total cost to produce the recharge water at roughly $1,000 per MG.

Future for Recharge

The future of groundwater recharge at St. Croix depends on the results obtained during this year's operation. To date, substantial data have not been collected regarding systems performance, long term infiltration rates, possible groundwater degradation, and the success of the program in halting saltwater intrusion.

LOS ANGELES COUNTY SANITATION AND FLOOD CONTROL DISTRICTS (WHITTIER NARROWS/SAN JOSE CREEK, CALIFORNIA)

Introduction

The Los Angeles County Sanitation District, in conjunction with the Central and West Basin Water Replenishment District, and the Los Angeles County Flood Control District, has been practicing groundwater recharge with effluent from its Whittier Narrows Wastewater Reclamation Plant since 1962. Additional effluent from the District's San Jose Creek plant has been used since 1972 for the groundwater replenishment program. Treated wastewater from the two plants is mixed with storm water runoff (when available), and imported state water prior to percolation on 690 wetted acres of basins in the Montebellow Forbay spreading area of the San Gabriel and Rio Hondo River Basins.

This recharge operation is the largest in the U.S. in terms of the volume of treated sewage percolated to the groundwater, an average of 25 mgd. All of the water that reaches the groundwater table (including the recharged effluent) is or eventually will be pumped out by water supplies in the central and west basins. This water comprises part of the municipal water supply for many communities in the area including, Los Angeles, Long Beach, Lakewood, and Downey.

It is virtually impossible for authorities to monitor the underground movement of the recharged water and to determine the amounts withdrawn by supply wells throughout the basin. However, community groundwater supplies drawn from immediately below the basins (i.e., Montebello, CA), may contain up to 15% reclaimed effluent (the percentage of treated wastewater in the mixed recharge water); while supplies taken further south in the basin area most likely contain only traces of effluent; if any at all.

Municipal Treatment

The Whittier Narrows and San Jose Creek plants are nearly identical in design. Both are step feed activated sludge treatment plants followed by chlorination Both are operated, at times, under excess aeration conditions to effect nearly complete nitrification.

Table A-20 on the following page summarizes typical effluent quality for these plants.

In order to prevent pollution of surface or groundwater, the Regional Water Quality Control Board has promulgated

Table A-20. AVERAGE MUNICIPAL EFFLUENT CHARACTERISTICS AT WHITTIER NARROWS AND SAN JOSE CREEK

Constituent	Concentration (mg/l)	
	Whittier Narrows	San Jose Creek
BOD	4	4.4
SS	7	8
TDS	597	687
MBAS	0.1	0.13
pH	7.0	7.1
Cl	93	154
Na	130	160
B	0.56	0.71
Fl	1.02	0.44
Cu	0.05	0.01
Fe	0.12	0.09
Mn	0.02	0.02
Cd	0.006	0.012
Cr	0.03	0.02
Pb	0.026	0.024
Se	0.007	0.006
Ag	0.004	0.002
Zn	0.064	0.062
As	0.013	0.012
Cn	0.02	0.024
Hg	0.0002	0.0003
Ni	0.13	0.02
NH_3-N	1.5	4.3
NO_3-N	14.4	12.3
NO_2-N	0.09	0.17
Org-N	2.1	1.8
Total N	17.8	18.6
Total PO_4 as PO_4	20	27
SO_4	113	107
Total coliform MPN/100 ml	42	2.4
Fecal coliform MPN/100 ml	10	2.0
SAR	563	---
Oil and grease	1.2	1.2
Phenolic compounds	0.006	0.004
Total pesticides	0.16	0.16

requirements for the Whittier Narrows and San Jose Creek discharges.

Under the NPDES program, the local Water Quality Control Board has established effluent limitations on the discharge to surface water from the two plants, some of which are summarized in Table A-21.

In addition, maximum limits on heavy metals, arsenic, cyanide, nitrogen, phenolic compounds, chlorinated hydrocarbons, and other constituents will become effective August 1, 1978.

Effluent used for groundwater recharge or landscape irrigation will have to meet the same requirements (legislation pending) as listed in Table A-21 with the following two exceptions: (1) wastes discharged shall not contain concentrations of heavy metals, arsenic, or cyanide in concentrations exceeding the limits contained in the State of California Department of Health Drinking Water Standards; and (2) the wastewater discharged must be adequately disinfected to a coliform MPN/100 ml of less than 23.

In addition, the State Department of Public Health has advised the WQCB that they believe, in order to protect the public health, the following conditions should be observed in reusing treated wastewater:

> "1. The public should be prevented from having contact with the sewage and sewage effluent.
>
> 2. The chemical and bacterial content of the sewage percolated into the groundwater should be regulated so that waters taken therefrom for domestic use are not contaminated.
>
> 3. Use of the sewage effluent for irrigation should comply with the provisions of the regulations of the State Department of Public Health.
>
> 4. The breeding of nuisance and/or disease vectors in the sewage effluent should be prevented.
>
> 5. A monitoring program of the effluent quality and the quality of the receiving waters should be maintained."

Recharge Program

Effluent from the Whittier Narrows and San Jose Creek plants flows from three to five miles to the Whittier Narrows Dam

Table A-21. NPDES EFFLUENT LIMITATIONS FOR WHITTIER NARROWS AND SAN JOSE CREEK PLANTS

Parameter	7-Day Average	Daily Max.
BOD (mg/l)	3.0	--
SS (mg/l)	40	--
Fecal (MPN/100 ml)	400	--
Oil and grease (mg/l)	10	15
Settleable solids	0.1	0.2
TDS	--	750
B	--	1.5
Cl	--	175
Coliform (MPN/100 ml)	2.2	--
pH	6.5 - 9.0	--

where it can be diverted by the Flood Control District as needed through a network of canals to the spreading grounds.

When storm water is available as natural runoff, a blend of water (approximately 10 to 15 percent effluent, 35 to 40 percent natural runoff, and 50 percent imported state water) is diverted to the spreading basins. During dry periods with little runoff, the mix of state water to effluent is two to one.

The two nearly adjacent spreading basins, San Gabriel and Rio Hondo, total 750 acres (Rio Hondo - 455 wetted acres; San Gabriel - 101 wetted acres of basin area, 133 acres of unlined river bottom, plus structures, facilities, unused area - 60 acres). All the effluent from the Whittier Narrows plant (an average of 15 mgd) is diverted to the Rio Hondo spreading area, while roughly one half of the 30 mgd San Jose Creek plant flow is channeled to the San Gabriel River area. The quantity of effluent diverted for recharge depends on precipitation patterns, and effluent TDS in the case of the San Jose Creek Plant.

The individual basins range from four to 20 acres in surface area and are interconnected with canal networks to allow for greater flexibility in the flooding schedule (i.e., several basins can be filled simultaneously or selected basins can be filled while others drain, etc.).

The Flood Control District rotates batteries of percolation basins for spreading purposes. Basins are filled for six days to an average depth of four ft (the San Gabriel River bed when used for spreading is flooded to an average two ft depth). The basins are then allowed to drain for six days and then to dry for six days to complete an 18-day cycle. Hence, at any given time, essentially one-third of the available acreage is being wetted. The combined capacity of both systems on a rotational basis is 200 mgd. During storm periods, when all basins are employed simultaneously, the combined capacity is over 600 mgd.

Soil profiles for the two recharge basins are shown in Table A-22. Soil materials are basically sandy loam above the groundwater table and bedrock below. Following the recharge flooding cycle described above, infiltration rates have averaged two ft per day with a range of 0.8 to five ft per day.

Percolation activities have created a "mounding" effect of the groundwater table such that depth to the groundwater table may be as little as ten ft directly under the recharge

Table A-22. GEOLOGIC SOIL PROFILES OF SAN GABRIEL AND RIO HONDO BASINS

San Gabriel Test Basin(1)

Depth below surface (feet)	Unit thickness (ft-in.)	From (ft-in.)	To (ft-in.)	At (ft-in.)	Description
0-	1' 10"	0	1' 10"	0	Dark brown very fine to medium silty sand and soil.
2-	2' 2"	1' 10"	4'	1' 10"	Light brown to tan fine to medium sand with lenses of gray fine sand. Moist, oxidized, orange fine sand streaks are common in tan portion.
4-	1' 6"	4'	5' 6"	4'	Wood fragments up to 3 in. long in dark brown to black medium to fine sand. Sand is highly micaceous.
6-	2' 2"	5' 6"	7' 8"	5' 6"	Tan fine to medium soft, micaceous sand, with gray fine sand lenses. Tan portions commonly show orange streaks of oxidized fine sand.
8-	4"	7' 8"	8'	7' 8"	Dark brown to black micaceous fine sandy silt stringer.
10-	1' 6"	8'	9' 6"	8' 8' 6"	Gray medium to coarse sand. Gray medium to coarse sand and "pea gravel" with occasional gravels to 3/8 in.

(1) Soil profile taken on 27 December 1962. Information supplied by the L.A. County Flood Control District.

Table A-22 (continued). GEOLOGIC SOIL PROFILES
OF SAN GABRIEL AND RIO HONDO BASINS

Rio Hondo Test Basin (2)

Depth below surface (feet)	Unit thickness (feet)	From (feet)	To (feet)	At (feet)	Description
0-					
	11	0	11		Tan fine to medium sand.
2-					
				3	Gray fine sand.
				3.5	Gray to tan medium sand.
4-					
				4	Occasional pebble.
6-					
				7	Trace of orange streaks/
8-					
				8.5	Micaceous material.
10-					
12-	3.5	11	14.5		Tan medium to coarse sand with 1/2 inch pebbles.
				12	Light orange color with pebbles.
				12.5	A few gravels to 2 inches.
				13.5	Occasional clay ball.
16-	2	14.5	16.5		Tan-gray medium sand. Water level at 16 feet.

(2) Soil profile taken on 11 December 1962. Information supplied by the L.A. County Flood Control District)

basins when the basins are in full operation, whereas, the average water table depth in the area is 50-60 ft.

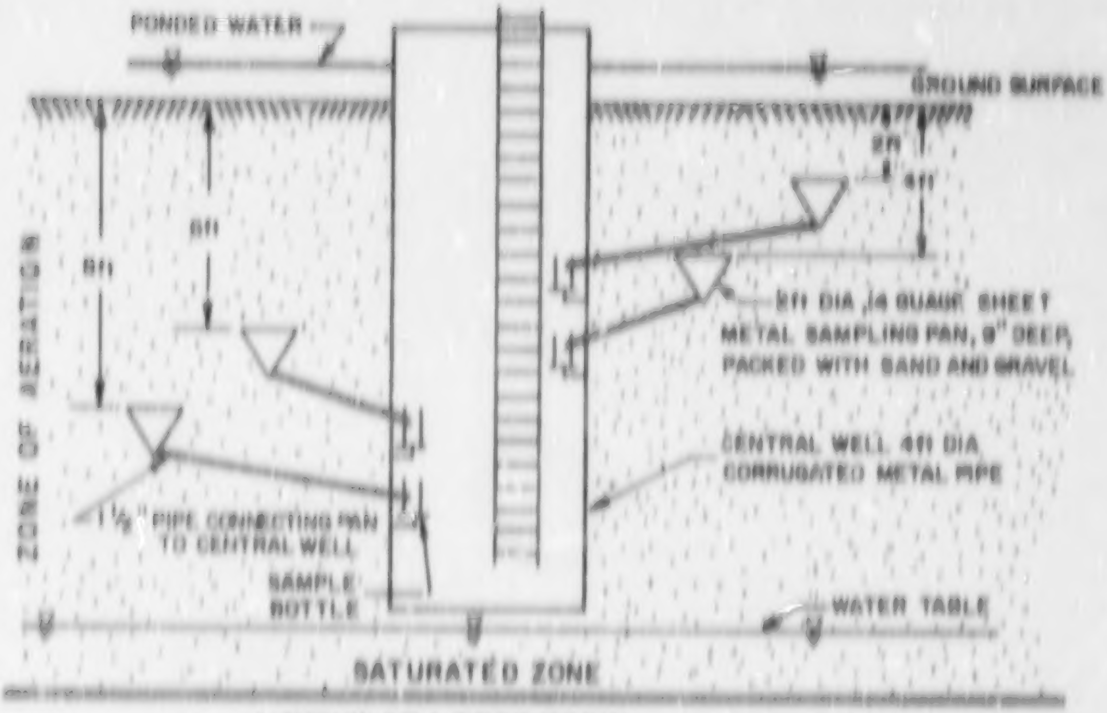
Chemical treatment (coagulation with a cationic polymer - Jaguar MRL22AA) is practiced at each forebay to eliminate silt problems. The first basin in both spreading areas serves as a desilting facility. In addition, basins in both spreading areas are scraped and scarified when necessary. It has been determined that vegetative growth enhances infiltration rates; hence, natural weed and grass growth has not been discouraged.

The rotational flooding program also aids in reducing insect and algae problems by interrupting life and growth cycles. When necessary, chemical treatment is also employed for insect control through a contract with the Southeast Mosquito Abatement District.

During the first few years of pilot operation with Whittier Narrows effluent (1963-1965), experiments were conducted in a test basin upstream of the spreading grounds with sample pans to collect recharged water at various depths to determine quality changes in the reclaimed water due to percolation. Figure A-16 shows a schematic diagram of the test basin and sampling apparatus. Although recent attempts to identify and sample percolating effluent directly beneath the full scale basins has been futile (due to dilution with other water sources and natural blending promoted by the mounding effect), past test results are felt to accurately characterize the current situation. Pertinent results from these tests are indicated below:

- Suspended solids were toally removed in the first few feet of percolation.

- 75 percent COD removal was exhibited in the first four ft; however, below four ft, the COD increased again to 40 percent of the surface concentration. One explanation for this phenomenon is that the COD naturally present in the soil (roughly 11,000 kg COD for a two-meter depth and 324 sq. m. basin surface area) appears to be higher than the total amount added by the recharge operations. It is possible, therefore, that organic carbon could be synthesized under anaerobic conditions in the soil system and that a portion of this organic carbon (probably in the form of bacterial bodies) could be leached downward to appear in the percolates at lower sampling pans.


PONDED WATER
GROUND SURFACE
2ft
4ft
8ft
6ft
ZONE OF AERATION
2ft DIA ,14 GUAGE SHEET METAL SAMPLING PAN, 9" DEEP, PACKED WITH SAND AND GRAVEL
CENTRAL WELL 4ft DIA CORRUGATED METAL PIPE
1 1/2" PIPE CONNECTING PAN TO CENTRAL WELL
SAMPLE BOTTLE
WATER TABLE
SATURATED ZONE

LAYOUT OF A TEST BASIN

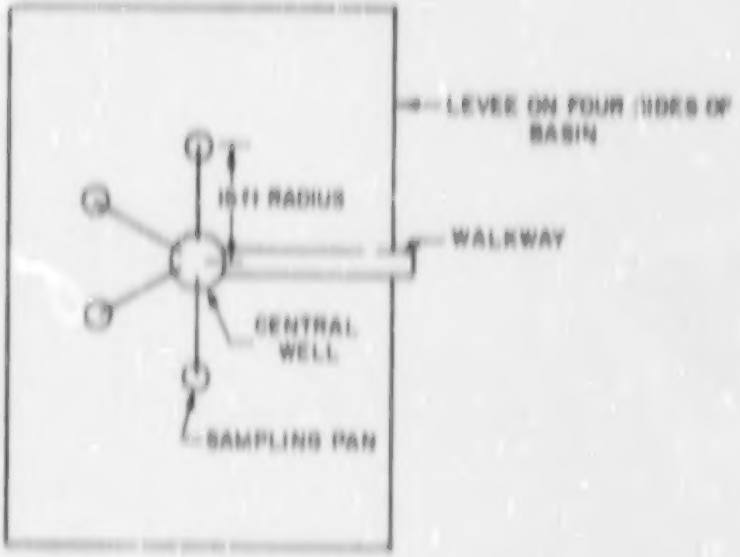

LEVEE ON FOUR SIDES OF BASIN
15ft RADIUS
WALKWAY
CENTRAL WELL
SAMPLING PAN

FIGURE A-16
SCHEMATIC OF A SAMPLING PAN WELL

- The sum of organic and ammonia nitrogen was reduced by 95 percent in the first two ft.

- Fecal coliforms were effectively removed. On the other hand, heavy growths of soil coliforms were generated, but it was postulated that those bacteria were removed by deep percolation and/or lateral travel in the zone of saturation.

- TDS increased slightly due to the leaching of minerals by weak nitrous acid formed during the intermediary steps of ammonia-to-nitrate conversion in the soil.

- Testing for viruses was inconclusive.

Groundwater levels and quality have been continually monitored throughout the program by a series of wells located in the basin area. Figure A-17 shows the location of the 31 well utilized for routine sampling. These wells are classified as shallow wells penetrating only the Gaspur Zone of aquifers near the surface (250 ft). This zone was of most interest because effluent introduced into the groundwater basin from spreading grounds first came in contact with groundwater in the Gaspur Zone. Each of the shallow wells was sampled on a routine basis with a 3-month to 6-month interval between samplings.

A special selective-depth pumping unit was fabricated by the Los Angeles County Flood Control District for sampling in the shallow wells. This special unit is portable and permits the collection of a water sample from a particular level in a well. Inflatable balloons or packers are positioned above and below the pump intake. When inflated, the packers close off the well above and below the pump intake so that water can be pumped from a particular level in a well. This type of operation permits the taking of water samples at multiple depths within a well. Limitations are caused by the spacing of the perforations in a cased well and the location of zones of impervious material. The purpose of sampling the shallow well network at multiple depths was twofold: first, to discover any changes in water quality attributable to the spreading of the reclaimed water; and second, to delineate, if possible, any near surface patterns in the groundwater movement. Because of the complex nature of the groundwater basin and the lack of any clearcut tracers in the effluent, the second purpose was not attainable. According to the results of the testing program, there have been virtually no adverse effects on groundwater quality due to the recharge of effluent mixed with natural runoff and

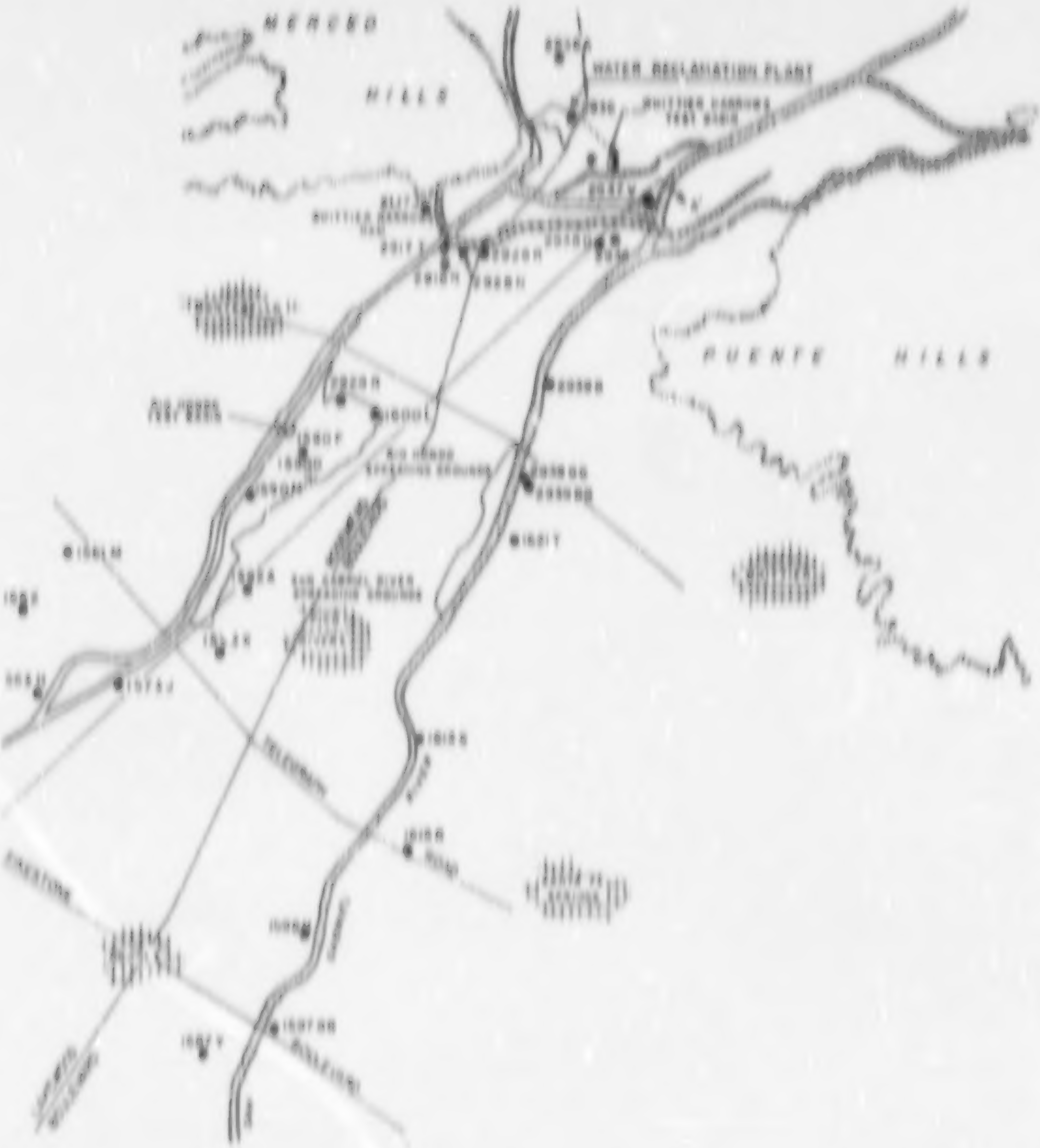

MERCED
HILLS
WATER RECLAMATION PLANT
WHITTIER NARROWS
TEST SITE
PUENTE HILLS
RIO HONDO
SPREADING GROUNDS
SAN GABRIEL RIVER
SPREADING GROUNDS
TELEGRAPH
ROAD
FIRESTONE

FIGURE A-17
LOCATION OF MONITORING WELLS
WHITTIER NARROWS WATER RECLAMATION PROJECT

imported state water. The only change has been a slight increase in groundwater TDS concentrations because the raw sewage has a TDS of over 600 mg/l.

The only minor problem reported by the Flood Control District due to the use of secondary effluent for recharge has been a reduction of infiltration rates when long term ponding has caused some basins to go anaerobic stimulating bacterial slime growth that sealed the soil surface. Problems with silt buildup decreasing infiltration rates are attributable to silt in the natural runoff waters, not the effluent.

Economics

Total costs to the Flood Control Districts for the recharge program only (based on the percolation of storm, reclaimed, and imported waters) were approximately $15 per MG. This cost is broken down as follows:

	$/mil gal (1972)
. Development and engineering	5.86
. Right-of-way	1.90
. Cleaning and repair	3.10
. Operation and maintenance	4.48
Total	$ 15.34

Purchase costs for the reclaimed water to be recharged are paid by the Central and West Basin Water Replenishment District to the Sanitation Districts and are estimated as shown below:

	$/mil gal	$/yr
Whittier Narrows effluent(1)	90	190,000
San Jose Creek effluent	15	27,000

---

(1) High price for Whittier Narrows effluent is due to contractual agreement with Water District to help subsidize and stimulate the initial effluent recharge program. This price will drop down to approximately $21/MG when capital costs for the Whittier Narrows plant are fully paid.

Thus, the Flood Control District gains needed water supplies and the L. A. County Sanitation District realizes a revenue of $220,000/year from the sale of treated wastewater.

Future for Recharge Programs

The future for groundwater replenishment programs using reclaimed water is uncertain in Los Angeles County at this time.

It can be assumed that the successful, established Whittier Narrows recharge operation will continue. However, doubts among officials of the California State Board of Health concerning the possible transmission of residual organics in secondary effluent to the groundwater have temporarily discouraged attempts to increase the volume of treated wastewater recharge by the L. A. Sanitation District.

One project that is currently in full scale planning following pilot studies is recharge of an operating oil field with reclaimed water to prevent subsidence and increase oil recovery. During pilot studies, the Los Angeles County Sanitation Districts verified that suspended and colloidal matter remaining in the secondary effluent from their Long Beach, California, plant would clog the shale rock pores. They concluded that relatively expensive tertiary treatment of the six mgd with polyelectrolytes, inert media filtration and disinfection (probably with ozone) to remove most of these impurities would be necessary to preserve infiltration rates and soil porosity.

Inert media filters will be added to the Long Beach plant in 1976 and the costs for additional tertiary treatment to make the water suitable for well injection are still under review. It is anticipated that 3 mgd of the filtered secondary effluent will be used by the City of Long Beach for park and golf course irrigation.

APPENDIX B

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APPENDIX C

WATER SANITATION SECTION
CALIFORNIA STATE DEPARTMENT OF HEALTH

POSITION ON BASIN PLAN PROPOSALS
FOR
RECLAIMED WATER USES INVOLVING INGESTION

September, 1973

WATER SANITATION SECTION
CALIFORNIA STATE DEPARTMENT OF HEALTH

POSITION ON BASIN PLAN PROPOSALS FOR RECLAIMED WATER USES INVOLVING INGESTION

Introduction

The purpose of the position statement is to provide guidelines for Department of Health review and recommendations on basin plan reclamation components that involve augmentation of a domestic water supply. The Department of Health responsibility is to represent the best health interests of the State in this matter by assuring protection of the domestic water resource.

Three uses of reclaimed water are considered in the statement:

1. groundwater recharge by surface spreading,
2. direct injection into an aquifer suitable for use as a domestic water source, and
3. direct discharge of reclaimed water for supply augmentation into a domestic water system or storage facility.

Health risks from the use of renovated wastewater may arise from pathogenic organisms and toxic chemicals. The nature of the phenomenon associated with pathogens and heavy-metal toxicants are well enough understood to permit setting limits and creating treatment control systems. This is not the case, however, with regard to some organic constituents of wastewater. In particular, the ingestion of water reclaimed from sewage may produce long-term health effects associated with the stable organic materials which remain after treatment.

This is an area of unknowns -- unknowns involving the composition of the organic materials, the types of long-term effects, synergistic effects, metabolite formations, treatment effects, methods of detection and identification, and ultimately, the levels at which long-term health effects are exerted.

The urgent need for knowledge in this area has generated increased calls for answers by health authorities, the water industry, resource managers, and the scientific community. It now appears that the need for research is recognized and there should be action in the near future. As a suggestion of the time frame needed for research activity, it has been estimated that the interval needed before information can be generated through animal feeding experiments (one possible method of study) could range from six to ten years or longer depending on the results that are obtained. The health effects of concern are not immediate or acute. They are related to ingestion over an extended period, measured in years or decades, and may be serious but quite subtle.

In summary, stable organics pose a health question when reclaimed water is used to augment a domestic water supply. This question will not be answered for years, and years of exposure may be involved for the occurrence of adverse effects. It is in this setting that the position statement has been developed.

Uses Involving Ingestion

Three uses of reclaimed water have been identified which involve augmentation of a domestic water supply. These are ranked in ascending order of health significance for the reasons given.

1. Groundwater replenishment by surface spreading.

   Health protection will depend on treatment, changes or removals which occur during percolation, dilution, and time.

   There are presently four planned recharge systems in operation in California which replenish aquifers used for domestic supply. The largest and one which has operated for more than a decade is the Whittier Narrows recharge operation which involves the recharge of 12,000-18,000 acre-feet of reclaimed water and 160,000 acre-feet of natural surface water annually into a large groundwater basin. The degree of monitoring to determine effects on the organic quality of groundwater from the several planned operations to this time has not been significant.

2. Injection into a groundwater aquifer.

   Health protection would depend upon treatment and time. There is little assurance that beneficial changes or removals will occur with horizontal movement through a saturated aquifer. Movement will most likely occur as a physical displacement of the natural groundwater with little mixing or dilution.

Most injection proposals thus far have been for the purpose of saline water repulsion. With mound and trough systems, there is opportunity for partial control of the movement of reclaimed water. The one proposal which has advanced to the construction stage (Orange County Water District) has a number of restrictive provisions and requirements applied to it including ". . . an alternate source of domestic water supply shall be provided any user whose groundwater is found to be impaired by the injection program." Two other proposals for saline water repulsion are in the development stage in California.

3. Direct discharge into the domestic water system.

Health protection would depend on treatment and dilution. Except for extreme situations where the lack of water has been of greater health significance than that associated with use of water reclaimed from wastewater, no responsible authority has embarked on deliberate, direct augmentation by introducing water reclaimed from sewage into the water system. There are proposals for the future.

The Basin Plans

In the Water Quality Control Plans, it is expected that reclaimed water use involving ingestion may be categorized in the following manner:

1. The plan involves an immediate or near-term decision regarding the reclamation element. Funds are to be committed to near-term physical facilities based on the decision and, once the selection has been made, the options are pretty well closed off. This is essentially an immediate "go or no go" decision.

2. The plan involves an immediate or near-term decision reagrding the reclamation element, however, there are reasonable options for other reclamation uses or for waste disposal employing the physical facilities. There will be some loss if the intended project is not completed in the proposed manner, however, regardless of eventual health findings the plan does not constitute an unalterable commitment to domestic supply augmentation.

3. The reclamation element is in a latter stage of the plan, 10 or more years in the future, and does not significantly affect earlier stages. A clear decision on health acceptability will ue available prior to construction.

There are, of course, many other shadings, but the three categories should suffice for general direction within which reasonable judgment can be applied.

Position on Plans for Direct Discharge into a Water System

A plan which involves direct discharge into a domestic water supply system or storage unit for the near future (within the next decade) is not acceptable because of the uncertain health implications. The Department will recommend against the element of a basin plan which contains such a proposal.

Where a plan requiring a near-term decision involves options or alternatives for the use or disposal of the wastewater, the Department will reject the domestic water reuse alternative and consider the remaining options as the proposals for evaluation.

Direct discharge into a water system may be presented in a plan as a future option which may be appraised as additional information becomes available and future needs and attitudes are clearer.

Position on Plans for Injection for Groundwater Replenishment

The Department will recommend against injection for groundwater replenishment as a plan element which is to be implemented in the near future (within next decade). Injection may be considered as a future option, contingent upon the availability of new supportive information and future needs.

Injection of reclaimed water for saline water repulsion and reclamation of saline aquifers is an acceptable use when accompanied by proper controls. Community domestic water supply may not be drawn from the immediate injection area and preferably, injection should be into the brackish water zone.

Position on Groundwater Recharge by Surface Spreading

Surface spreading appears to have the greatest potential for use of reclaimed water in the basin plans. It is expected that most groundwater recharge will be through this method since surface spreading involves the least cost and has the greatest history of practice.

Although this potential exists, it must be restated that there are no reclamation criteria for domestic use of reclaimed water, information relative to health effects from ingestion is uncertain and the interval involved before conclusive information is available may be considerable. It should also be emphasized that if new information indicates adverse effects are created with substantial recharge, closure of those basins involved would be required with regard to domestic use.

The application of limits on specific percentages of reclaimed water allowable in groundwater would be inappropriate because knowledge of health effects is lacking.

For near-term proposals, plans which involve the recharge of a substantial volume of reclaimed water into a small basin will be recommended against.

If information indicates uncertain or adverse effects are associated with recharge operations of this magnitude, the results would require a costly effort to reclaim the basin or might result in abandonment of the basin for domestic use. The serious implications of this situation, therefore, require the Department of Health to recommend against such a proposal.

Where recharge operations would constitute a small fraction of water in the underground, near-term proposals may be acceptable. Location relative to community wells will be considered as well as the domestic use of the basin waters. By limiting such proposals to operations involving only small percentages of reclaimed water in the groundwater, the corrective action, if required, may be without undue cost or loss of the basin as a domestic source. Near-term plans with available options to surface spreading are desired.

Surface spreading presented as a future option in a plan would be acceptable.

APPENDIX D

CAPITAL COST FACTORS

The following factors were used to convert all capital costs to equivalent 1972 dollars.

Year	Conversion Factor
1957	1.75
1958	1.69
1959	1.66
1960	1.64
1961	1.63
1962	1.61
1963	1.53
1964	1.56
1965	1.54
1966	1.48
1967	1.44
1968	1.39
1969	1.30
1970	1.20
1971	1.08
1972	1.00
1973 (Jan.)	0.91
1974 (Nov.)	0.79

To obtain cost in 1972 multiply actual cost by conversion factor given above for the year of actual construction.

1957-1972 cost factors were derived from FWPCA, Department of Interior, Dec., 1967, and Treatment Optimization Research Program, Advanced Waste Treatment Research Laboratory, Cincinnati, OH. 1973, 1974 cost factors were derived from ENR Construction Cost Index.

APPENDIX E

PROCEEDING FOR COST CALCULATION

The following steps were used to determine final $/MG costs for recharge:

- Convert recharge facilities capital costs to equivalent 1972 dollars using Appendix D.
- Calculate annual capital recovery factor by multiplying equivalent 1972 cost by 0.07455 (capital recovery factor assuming 5.5 percent interest and 25 year life).
- Add equivalent 1972 annual recharge operation and maintenance cost to annual capital recovery cost.
- Divide resultant total annual cost by 365 days x MGD to get final $MG for recharge.

APPENDIX F

CONVERSIONS FROM CUSTOMARY UNITS TO METRIC

Customary Units		Multiplier	Metric Units	
	Symbol		Symbol	
Description	Multiply	By	To Get	Reciprocal
Acre	ac	0.4047	ha	2.471
British thermal unit	Btu	1.055	kJ	0.9470
British thermal units per cubic foot	Btu/cu ft	37.30	J/l	0.02681
British thermal units per pound	Btu/lb	2.329	kJ/kg	0.4295
British thermal units per square foot per hour	Btu/sq ft/hr	3.158	J/m^2sec	0.3167
Cubic foot	cu ft	0.02832	m^3	35.31
Cubic foot	cu ft	28.32	l	0.03531
Pounds per thousand cubic feet per day	lb/1000 cu ft/day	0.01602	kg/m^3 day	62.43
Cubic feet per minute	cfm	0.4719	l/sec	2.119
Cubic feet per minute per thousand cubic feet	cfm/1000 cu ft	0.01667	l/m^3 sec	60.00
Cubic feet per second	cfs	0.02832	m^3/sec	35.31
Cubic feet per second per acre	cfs/ac	0.06998	m^3/sec ha	14.29
Cubic inch	cu in.	0.01639	l	61.01
Cubic yard	cu yd	0.7646	m^3	1.308
Fathom	f	1.829	m	0.5467
Foot	ft	0.3048*	m	3.281
Feet per hour	ft/hr	0.08467	mm/sec	11.81
Feet per minute	fpm	0.00508	m/sec	196.8
Foot-pound	ft-lb	1.356	J	0.7375
Gallon	gal	3.785	l	0.2642

APPENDIX F(Continued)

Customary Units		Multiplier	Metric Units	
	Symbol		Symbol	
Description	Multiply	By	To Get	Reciprocal
Gallons per acre	gal/ac	0.00935	m^3/ha	106.9
Gallons per day per linear foot	gpd/lin ft	0.01242	m^3/m day	80.53
Gallons per day per square foot	gpd/sq ft	0.04074	m^3/m^2 day	24.54
Gallons per minute	gpm	0.06308	l/sec	15.85
Grain	gr	0.06480	g	15.43
Grains per gallon	gr/gal	17.12	mg/l	0.05841
Horsepower	hp	0.7457	kW	1.341
Hoursepower-hour	hp-hr	2.684	MJ	0.3725
Inch	in.	25.4*	mm	0.03937
Knot	knot	1.852	km/h	0.5400
Knot	knot	0.5144	m/sec	1.944
Mile	mi	1.609	km	0.6215
Miles per hour	mph	1.609	km/h	0.6215
Million gallons	mil gal (MG)	3785.0	m^3	0.000264
Million gallons per day	mgd (MGD)	43.81	l/sec	0.02282
Million gallons per day	mgd (MGD)	0.04381	m^3/sec	22.82
Ounce	oz	28.35	g	0.03527
Pound (force)	lbf	4.448	N	0.2248
Pound (mass)	lb	0.4536	kg	2.205
Pounds per acre	lb/ac	1.121	kg/ha	0.8921
Pounds per cubic foot	lb/cu ft	16.02	kg/m^3	0.06242
Pounds per foot	lb/ft	1.488	kg/m (KG/m)	0.6720
Pounds per horsepower-hour	lb/hp-hr	0.1690	mg/J	5.918
Pounds per square foot	lb/sq ft	4.882	kgf/m^2	0.2048

APPENDIX F (Continued)

Customary Units		Multiplier	Metric Units	
	Symbol		Symbol	
Description	Multiply	By	To Get	Reciprocal
Pounds per square inch	psi	703.1	kgf/m^2	0.001422
Pounds per square inch	psi	6.895	kN/m^2	0.1450
Square foot	sq ft	0.09290	m^2	10.76
Square inch	sq in.	645.2	mm^2	0.001550
Square mile	sq mi	2.590	km^2	0.3861
Square yard	sq yd	0.8361	m^2	1.196
Ton, short	ton	0.9072	t	1.102
Yard	yd	0.9144*	m	1.094

*Indicates exact conversion factor.

Note: The U.S. gallon is assumed. If the conversion from the Imperial gallon is required, multiply factor by 1.201.

Standard gravity, $g = 9.80665^{*}\ m/s^2$

$= 32.174\ ft/s^2$.